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A STUDY OF THE RADIATIONS EMITTED BY A RIGHI VIBRATOR.

By Harley R. Willard and L. Elmer Woodman.

I. Introduction.

There are two views regarding the nature of the radiation emitted by a Hertz vibrator. Sarasin and de la Rive,[1] Garbasso,[2] and others,[3] interpreting their experiments, came to the conclusion that each vibrator sends out all wave-lengths within certain wide limits, and that each resonator picks out from these different vibrations the one corresponding to its own period. The name of "multiple resonance" was given to this phenomenon.

Poincaré,[4] Bjerkness,[5] and others[6] have a different view. They are of the opinion that each vibrator sends out only vibrations of a single period which are highly damped, and that the "multiple

[1] Sarasin and de la Rive, Compt. Rend., p. 439, 1892.

[2] Garbasso, Journal de Physique, Vol. 22, p. 259, 1893.

[3] Waitz, Wied. Ann., Vol. 41, p. 435–447; Geitler, Wied. Ann., Vol. 66, p. 999, 1898; Gutton, Journal de Physique, Dec. 1901, p. 752; Klemencic and Czermak, Wied. Ann., Vol. 50, p. 175; Trouton, Nature, Vol. 41, p. 295, 1890; Garbasso and Aschkinass, Wied. Ann., Vol. 53, p. 534; Swingedauw, Arch. des Sci. Phys. et Nat. de Geneve, Vol. 3, p. 476, 1897; St. John, Phil. Mag., Vol. 88, p. 425, 1894; Lamotte, Journal de Physique, Oct. 1901, p. 589.

[4] H. Poincaré, "Electricité et Optique," Vol. 2, p. 250.

[5] Bjerkness, Wied. Ann., Vol. 44, p. 92, 1891.

[6] Bose, Phil. Mag., Vol. 43, p. 55; Drude, Journal de Physique, Vol. 26, p. 643; Wied. Ann., Vol. 61, p. 631, 1897; Arch. des Sci. Phys. et Nat. de Geneve, Vol. 3, p. 554, 1897; Strindberg, Journal de Physique, Vol. 24, p. 142, 1895; Planck, Wied. Ann., Vol. 60, p. 577, 599, 1897; Decombe, Journal de Physique, Vol. 28, p. 450, 1899; Hertz, "Electric Waves."

resonance" effects observed by Sarasin and de la Rive and others are due to the damped character of these vibrations. They support these views by theory and experiment.

The experiments described in this paper were undertaken for the purpose of determining: (*a*) the nature of the radiation emitted by a Righi vibrator; (*b*) the dependence of the length of a linear receiver upon the wave-length with which it is in resonance. This problem, however, resolved itself into: (1) the measurement of the energy received from the same vibrator by resonators of different lengths, and (2) the measurement of the wave-lengths obtained with different resonators.

II. THE APPARATUS.

The Vibrator. — Two Righi[1] vibrators were used in these experiments, one twice the linear dimensions of the other. The mounting and arrangement of parts is shown in Fig. 1. Spheres 3 and 4

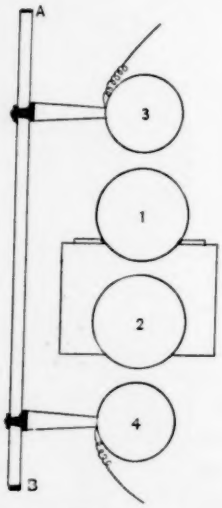


Fig. 1.

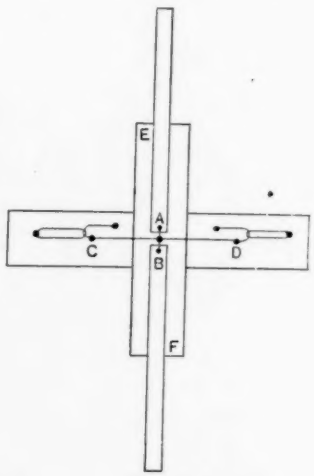


Fig. 2.

were fastened to the glass rod *AB* by means of hard rubber rods, and to these spheres were attached the lead wires from the induction coil. Spheres 1 and 2 were supported in a glass cylinder filled with olive oil. This makes two spark-gaps at which the spark passes in air, and one at which the spark passes in oil. It is the

[1] Righi, Mem. del R. Acad. dei Sc. del Inst. di Bologna, T. IV. 1894.

latter discharge which sets up the train of waves studied in these experiments, although there seemed at times to be good reasons for thinking that the other discharges also caused wave trains which had more or less effect upon the receiver.

In the smaller vibrator the spheres 3 and 4 were 20 mm. in diameter and the spheres 1 and 2 were 25.4 mm. In the larger vibrator the diameter of the smaller spheres was 20 mm., and of the larger 50.8 mm. The large spheres had to be taken out and polished frequently because the energy of the vibrations fell off rapidly as the surface of the spheres at the spark-gap deteriorated.

The Receiver. — The receiver used was very similar to the Klemencic thermo-element used by A. D. Cole.[1] Fig. 2 shows the general construction of a thermo-junction, various modifications of which were used. Two strips of copper foil were fastened by means of shellac to two of the arms of a wooden cross *EF*. To one of the copper strips an iron wire 0.04 mm. in diameter was soldered, and to the other a constantan wire 0.107 mm. in diameter. At the middle of the gap, between the copper strips the wires were crossed and the ends soldered at *C* and *D* to copper wires leading to the galvanometer. The copper wires were carried back on each side through holes in the wooden cross, leaving loops through which rubber bands were passed. Good contact between the wires of the thermo-junction was obtained by keeping the rubber bands extended. The resistance of such a thermo-junction was about one ohm.

The Parabolic Mirrors. — The vibrator and receiver were each placed in the focal line of a cylindrical parabolic mirror. Two pairs of mirrors were used. With the vibrator having the 2.54 cm. spheres the mirrors were 30 cm. high by 38 cm. wide, and of 3.7 cm. focal length. The other mirrors used with the vibrator having the 5.08 cm. spheres were 64 cm. high by 90 cm. wide a the opening, and of 10 cm. focal length.

In the determination of the energy curves, given later, the length of the receiver was shortened between successive series of measurements. To accomplish this with the least jar or disturbance to the thermo-junction, the receiver was attached to a glass tube which passed through a hole in the back of the mirror and which carried

[1] A. D. Cole, PHYSICAL REVIEW, Vol. IV., No. 19. July-August, 1896.

the wires connecting the receiver to the galvanometer. The receiver could thus be easily removed, the ends shortened, and again replaced.

The Galvanometers. — The galvanometers were four-coil reflecting galvanometers of the Thomson type. The resistance of the four coils connected in multiple was five ohms. The sensitiveness of galvanometer A was 8×10^{-9} and of galvanometer B 4×10^{-9}, for a period of twelve seconds.

The arrangement of the apparatus in the first series of experiments is shown in Fig. 3. The two galvanometers are shown at

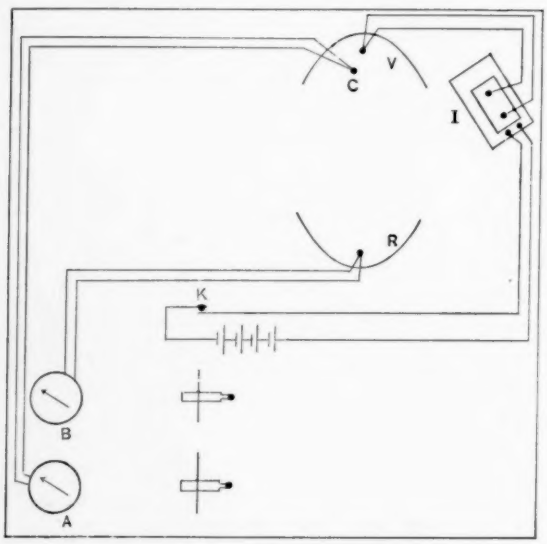


Fig. 3.

A and B. The relative positions of the vibrator and receiver mirrors are at V and R. The distance between the vibrator and receiver was varied until the radiation falling on the receiver in the mirror R, gave a convenient working throw of galvanometer B. The induction coil was placed at I. The disturbing influence of the induction coil upon the galvanometers was reduced to a minimum by rotating the coil and a correction was added to the galvanometer deflections for the uneliminated disturbance, which was small. The circuits leading to the galvanometers were twisted to prevent any disturbance from induced currents.

Accidental thermal disturbances were eliminated as far as possible by wrapping all connections in cotton and by placing sheets of cardboard over the apertures of the mirrors.

To eliminate variations in the intensity of the emission of the vibrator, the plan of Klemencic and Czermak[1] of a "control" receiver (*c*, Fig. 3) placed in the vibrator mirror was adopted. No change was made is this thermo-junction during any one series of readings. Its lead wires were attached to galvanometer *A*. In each set of readings the throws of both galvanometers were taken and the ratios of the two throws were very nearly constant for any one set of conditions. After taking these precautions the sets of readings were consistent in themselves, and also from day to day.

Before each series of measurements the two galvanometers were carefully adjusted to the same period. This adjustment under ordinary circumstances held for an hour or more without change, thus giving ample time for the determination of the ratios for any one receiver length. Before each observation conditions of quiet for both galvanometers were awaited. A key closing the primary circuit of the induction coil was then pressed and the vibrator held in operation until the end of the first throw of the galvanometers. The key was then opened and the turning point of the return throw observed. The difference between the scale reading of the turning point of the first throw and the mean of the zero position and turning point of the return swing was taken as the deflection. To the deflection thus obtained small corrections were added to eliminate the slight disturbing action of the induction coil upon the needle systems.

Ordinarily ten observations constituted a series and the mean of the ratios of the deflections of the two galvanometers determined the ratio for one length of the receiver. The note-book record of one such series is shown entire in Table I.

In this way ratios were obtained for different lengths of the receiver, varied by steps from 173 mm. to 16 mm. These ratios are exhibited in Table II. and plotted as an energy curve in No. 2, Fig. 4, in which receiver lengths are shown as abscissæ and ratios as ordinates.

This operation was repeated with three other receivers of varying widths and construction using the smaller vibrator, and also with three different receivers, using the larger vibrator as a source.

[1] Klemencic and Czermak, Wied. Ann., Vol. 50, p. 175.

TABLE I.

Feb. 27, 1902. *Period* 14.2 *sec. Length of Each Copper Strip* 14.5 *mm. Total Length of Thermo-Junction* 32 *mm.*

Galvanometer A.					Galvanometer B.					
Return Swing.	Zero.	First Turning Point.	Deflection.	Corrected Deflection.	Return Swing.	Zero.	First Turning Point.	Deflection.	Corrected Deflection.	Ratio of Deflections.
25.75	29.05	33.45	6.05	5.68	20.00	20.80	22.40	2.00	1.92	.338
25.95	29.05	33.35	5.85	5.48	20.05	20.80	22.40	1.97	1.89	.345
25.95	29.24	33.65	6.05	5.68	20.04	20.80	22.50	2.08	2.00	.352
26.00	29.38	33.95	6.26	5.89	19.97	20.80	22.50	2.11	2.03	.345
25.70	29.70	34.95	7.25	6.88	19.80	20.78	22.74	2.45	2.37	.344
26.35	29.90	34.65	6.52	6.15	19.65	20.50	22.25	2.17	2.09	.340
26.65	30.35	35.30	6.80	6.43	19.14	20.10	22.00	2.38	2.30	.358
26.70	30.62	35.90	7.24	6.87	18.80	19.80	21.80	2.50	2.42	.352
26.85	30.66	35.85	7.09	6.72	18.84	19.82	21.80	2.47	2.39	.356
27.35	30.90	35.65	6.52	6.15	18.84	19.70	21.50	2.23	2.15	.350
27.35	31.10	36.10	6.87	6.50	18.68	19.60	21.48	2.34	2.26	.348
									Mean	.348

TABLE II.

Total Length of Resonator.	Ratio Galv. B. / Galv. A.	Total Length of Resonator.	Ratio Galv. B. / Galv. A.	Total Length of Resonator.	Ratio Galv. B. / Galv. A.
173	.366	77	.972	31	.263
161	.382	73	.882	29	.307
152	.386	59	.603	27	.241
142	.408	49	.476	25	.211
133	.438	45	.434	23	.212
113	.570	43	.400	21	.140
93	.883	41	.360	19	.144
89	.922	39	.375	17	.165
85	1.003	37	.297	16	.073
81	1.022	33	.298		

Discussion of the Energy Curves. — The curves 1 to 4, Fig. 4, were obtained by using the smaller vibrator, operated by a 10 cm. spark length induction coil driven by four storage cells. The receiver and vibrator were 152 cm. apart. The same "control" receiver (*c*. Fig. 3) was used for the four curves. The copper strips on this

thermo-junction were each 4.4 mm. wide and 30 mm. long. The space between the two copper strips was 2 mm., making the total receiver length equal to 62 mm. The small iron and constantan wires were soldered at the junction so that no tension was required to insure contact. This "control" receiver was placed 9 cm. in front of the spark gap of the vibrator.

The characteristic points on energy curves 1, 2, 3 and 4 are shown in Table III. with specifications of the receiver used in each case.

TABLE III.

	No. 1.	No. 2.	No. 3.	No. 4.	Mean.
Width of resonator strips.	4.6 mm.	4.6 mm.	No. 18 Cu wire.	3 mm.	
Length of fine wire connecting resonator halves.	3 mm.	3 mm.	1.6 mm.	2.3 mm.	
First maximum.	80.0?	82.5	81.5	80.5?	81.1
Second "	41.5	39.0	41.5	40.2	40.55
Third "		29.0	26.0?	29.0?	28.0
Additional maxima.					
1.			51.9	56.5	54.2
2.		17.0		18.0?	17.5
3.				70.2	70.2

As the ratio of width to length in the shortened receivers was relatively large, receivers of different widths were studied to discover any effect upon the energy curves traceable to a greater or less constriction of the stream lines traversing the thermo-junction.

The curves apparently show either an emission of the vibrator corresponding to a damped fundamental vibration with one, two, or three less clearly-marked maxima, some of which stand in nearly the same numerical relation to the fundamental as upper partial vibrations in a stretched string; or the emission of a continuous spectrum with accented fundamental and upper partial vibrations. The former interpretation corresponds to the conclusions drawn by Bjerkness, Poincaré and others, and the latter to the views of Sarasin and de la Rive and their followers. So far as the writers are aware, none of the above investigators took any account of upper partial vibrations.

In the first curve a fundamental and the first upper partial not very clearly marked appear. The thermo-junction was accidentally

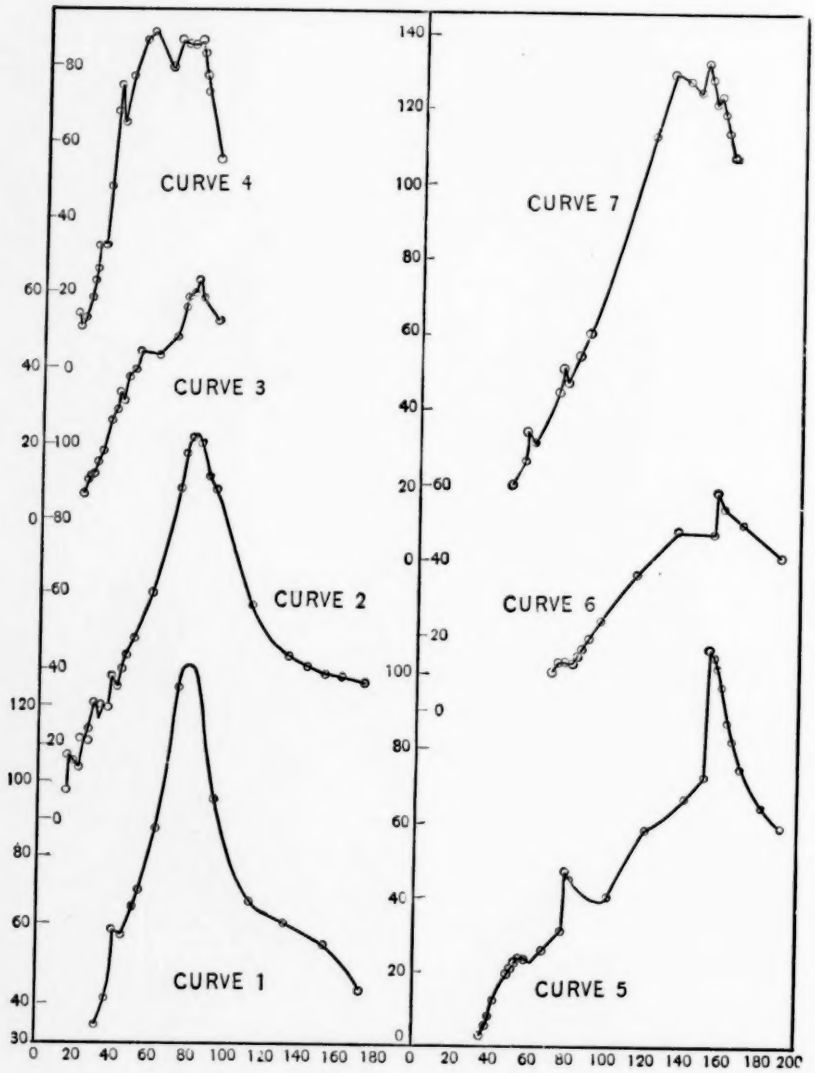


Fig. 4.

broken in the process of shortening the receiver just before the length corresponding to the second upper partial was reached. So few points were observed on this curve in the region of the maxi-

mum corresponding to the fundamental vibration as to leave the receiver length corresponding to this maximum somewhat in doubt.

The second curve was the most characteristic one secured. It shows a well-defined maximum corresponding to a fundamental and two fairly distinct maxima corresponding to the first two upper partials.

In curve 3 the course of the energy curve is less regular, but the fundamental and first two upper partial maxima appear. For a receiver length of about 26 mm. a doubtful maximum occurs.

Curve 4 is the least satisfactory of the group in that the fundamental maximum appears to be very complex and not sharply defined. At the point corresponding to what has been called the first upper partial on the foregoing curves, a well-defined maximum appears. At the position corresponding to the second upper partial in curve 2, there is only a slight kink in the curve. At a receiver length of 18 mm. indications of an additional maximum appear, but the thermo-junction was unfortunately broken in handling before its position was defined. It resembles, however, in position the last maximum on curve 2, which is not far from the position for a third upper partial.

Curves 3 and 4 show maxima at one or two other points in their length, which are recorded in the table as additional maxima.

In order to see if there was any simple linear relation between the length of receiver giving the fundamental maximum and the diameter of the larger spheres in the vibrator, energy curves 5, 6 and 7 were obtained in the same manner, but using a vibrator in which the diameter of the larger spheres was twice as great. For curves 5 and 6 the vibrator was operated by the same induction coil as for the first four curves. The "control" receiver (*c.* Fig. 3) was made of copper strips 4 mm. wide, with a space of 1.5 mm. between them, making the total length of the receiver 163.5 mm. It was placed 18 cm. in front of the spark gap. The distance between the focal lines of the parabolic mirrors was 187 cm. for curve 5 and 150 cm. for curve 6. For curve 7, a 20-cm. spark-gap induction coil driven by 21 storage cells was used. It was placed in another room about 110 feet from the vibrator and rotated so as to reduce to a minimum the magnetic effect upon the galvanometers.

The "control" receiver was cut down to 158 mm. and the vibrator and receiver were placed 273 cm. apart.

Table IV. gives the dimensions and details of construction of the three thermo-junctions used and also the total receiver lengths corresponding to the maxima on the three curves.

Curve 5 shows a very distinct fundamental and two upper partials. The maximum of the second upper partial is so broad that it

TABLE IV.

	No. 5.	No. 6.	No. 7.	Mean.
Width of resonator strips.	4 mm.	4 mm.	4 mm.	
Length of fine wire connecting resonator halves.	2 "	2 "	1.7 "	
1st Maximum.	154	158	156?	156.0
2d "	80	79?	76	78.3
3rd "	56?		58	57.0
Additional Maxima.				
1.			148	148
2.			131	131

is difficult to determine just what receiver length would correspond to it, but the first upper partial gives a very distinct maximum on the curve.

Curve 6 shows a sharp maximum for the fundamental, and one upper partial, not so clearly marked as the corresponding one in curve 5.

Curve 7 is more complex around the fundamental than either of the other two. By comparing it with curves 5 and 6 it seems that the slight elevation on the right side of the curve may be the fundamental but the evidence is not convincing. There are, however, two upper partials present which correspond very closely with the upper partials of curve 5. In this curve there are two additional maxima which seem to have no simple relation to the assumed fundamental, and two upper partials.

A study of these three curves, as well as of the four curves obtained with the smaller vibrator, seems to show that the fundamental radiation sent out by a Righi vibrator becomes more complex the longer the vibrator is used in spite of the fact that the surfaces in oil were frequently repolished.

The smaller secondary maxima occur upon the steeply descending sides of the general energy curve and it might therefore be expected that some displacement toward the side of a longer receiver should be looked for. Although this might explain the apparent displacement of the second upper partial in the longer vibrator, no plain evidence of it can be detected in the corresponding upper partial of the smaller vibrator. On the other hand, the shorter receiver actually takes up less energy than a longer receiver. If the energy readings are divided by the length of the receiver, the curve would not fall so rapidly and the observed maxima would be displaced toward the shorter lengths and would be more pronounced. Other conditions which might alter the position of maxima on the curves are :

First, the resistance in the thermo-junction of the receiver might be changed by a jar or strain in clipping off the ends between two series. The greatest care possible was exercised in this process to avoid any shocks or strains which might produce such a change of resistance.

Second, any change or deterioration in the spark gap of the vibrator producing a change in its emission might not affect both receivers in the same degree.

Third, in comparing the receiver lengths for the fundamental and upper partial vibrations, it must be borne in mind that the ratios of width to length of the receivers were very different for the different lengths.

It is very probable that the results obtained in these experiments are not due to the vibrator alone, but rather to the combined action of vibrator and receiver. The fact that the curves all show a fundamental and one or more upper partials when the receiver was changed and the vibrator was kept the same, seems to show that the form of the curve was determined more by the characteristics of the vibrator than by those of the receiver.

While the experimental data is insufficient to warrant rigid conclusions, it is worthy of notice that the ratio of the diameters of the large spheres in the two vibrators is very nearly equal to the ratio of the receiver lengths which correspond to the fundamentals, as determined from the energy curves. The work with the interferom-

eter, which is given in the next section, was taken up to determine whether the same ratio would hold between the fundamental wave-lengths emitted by the two vibrators.

III. INTERFEROMETER FOR MEASURING WAVE-LENGTHS.

In measuring the wave-length of our vibrations, we made use of the interferometer, as arranged by G. F. Hull,[1] in 1896. A description of the instrument will be given below. The interferometer seemed best for our use. In the Quincke tube arrangement, λ has been found by Drude to depend upon the diameter of the tube. On this account the Quincke tube was not adapted to the conditions of our experiment.

The relatively long path between receiver and vibrator in the Boltzmann mirrors and the shadowing of one mirror by the other, cause a diminution of energy and give poor conditions for interference. There is no such shadowing in the interferometer, and the distances can be made relatively small without affecting the success of the experiment. The plan of the interferometer is shown in Fig. 5.

The mirrors V and R, containing the vibrator and receiver, are those described in Part II. M_1 and M_2 are plane mirrors for reflecting the waves at normal incidence. They were constructed of wood and covered with tin foil. When the smaller vibrator was used, these mirrors were 51 cm. long by 38 cm. high. When the larger vibrator was used, the mirrors were 111 cm. long by 70 cm. high. Difference of path was obtained by the movement of M_2 along the ways T, and distances were measured by means of the scale W. The separating surface[2] S was made of strips of tin one cm. wide and of varying lengths so that the whole separating sur-

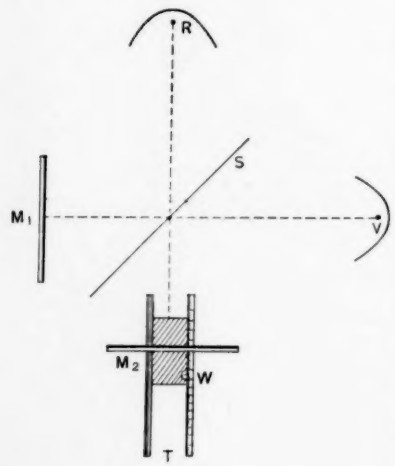
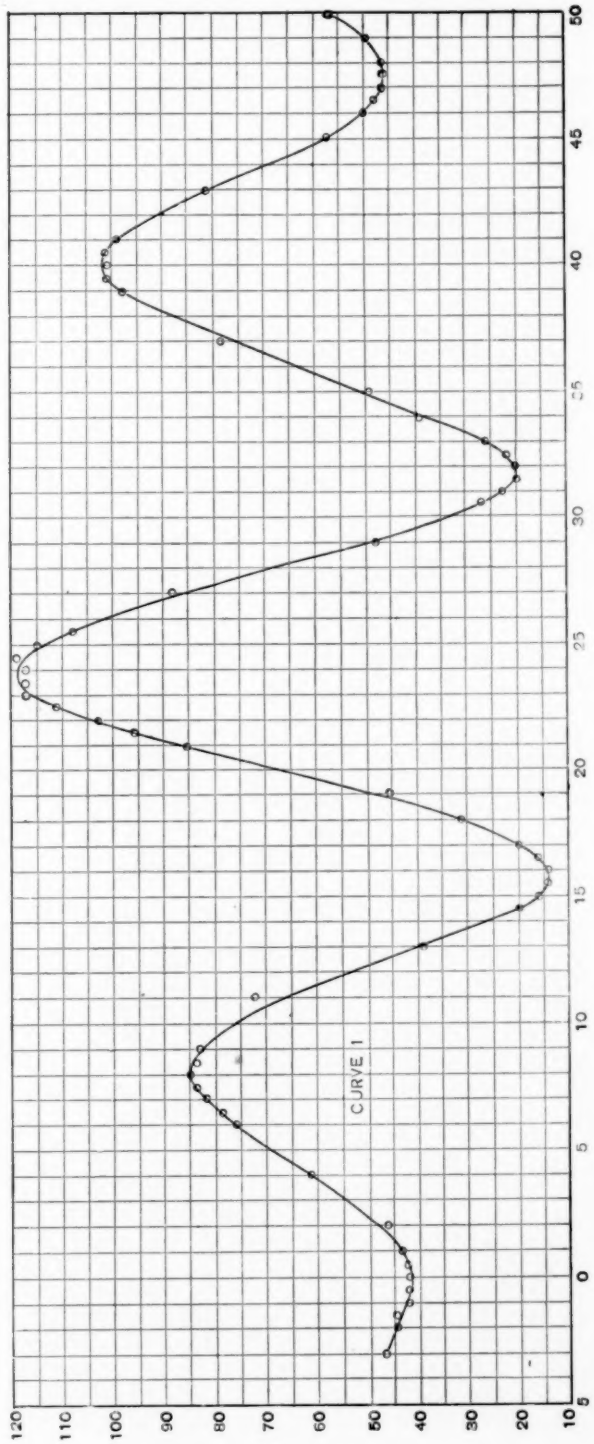


Fig. 5.

[1] G. F. Hull, PHYSICAL REVIEW, Vol. 28, 1897.

[2] G F. Hull, l. c.


CURVE 1
120
110
100
90
80
70
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50
40
30
20
10
0
5
10
15
20
25
30
40
45
50

face would not be in resonance with any particular wave-length. They were hung over an iron rod and were held in one plane at the bottom by a strip of wood. The grating space — the distance between the centers of the strips — was changed for each receiver to secure equality between transmission and reflection. To determine the grating space, the mirrors M_1 and M_2 were removed, and the positions of the tin strips were adjusted until the energy reflected

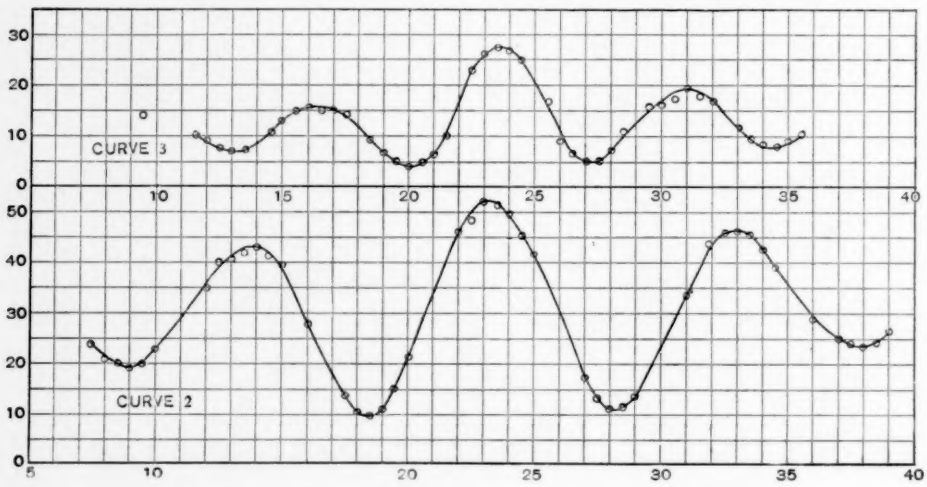

Fig. 7.

from the grating was equal to the energy transmitted. A graduated force table was used for measuring angles.

In curve 1, Fig. 6, it was found that the condition for equal reflection and transmission was obtained when the grating space was equal to 12 cm.; in curves 2, 3 and 4, Figs. 7 and 8, when it was equal to 8 cm., 6 cm. and 8.9 cm., respectively.

When the grating space had been determined for each vibrator and receiver, the vibrator was placed in its mirror and a resonator of the required dimensions was constructed and placed in the focal line of the receiving mirror. The mirrors were then arranged as indicated in Fig. 5.

The frequent repolishing of the vibrator spheres usually did not affect the ratios of the two galvanometer throws, but sometimes it caused a deviation of a few per cent. which resulted in an upward

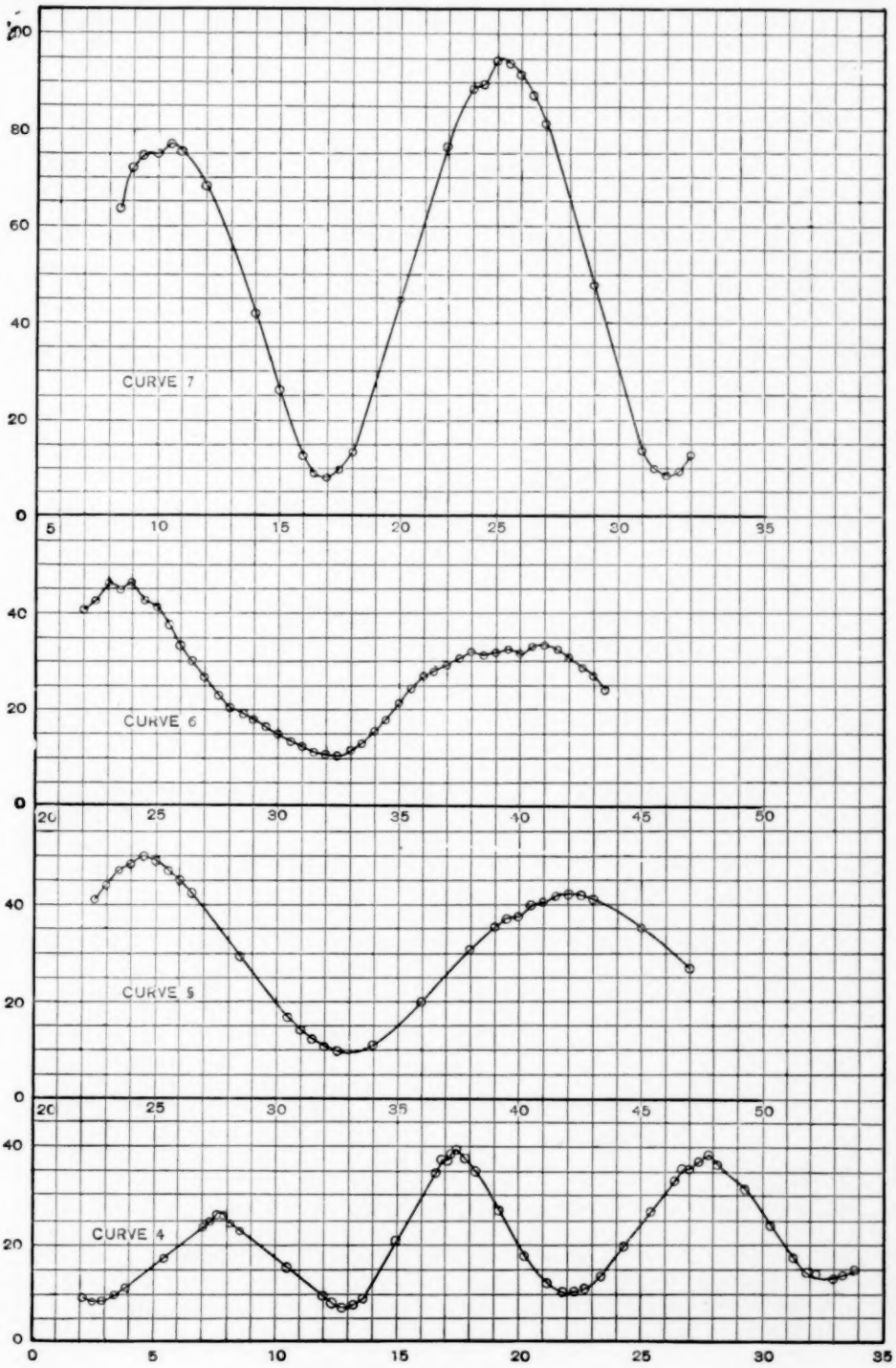

Fig. 8.

or downward displacement of the interference curve. The vibrator was never disturbed while working in the regions of the maxima and minima, so that any variation of ratio would not affect the value of the wave-length.

The Measurement of Wave-lengths. — The measurement of the wave-length consisted in taking readings for different positions of the movable mirror, going through the whole curve and retracing the path, and from these readings in plotting an interference curve. The curve consisted of well-marked maxima and minima, and the distance between two maxima or two minima was equal to one half wave-length of the vibration. The readings on the scale of the movable mirror were used as abscissæ of the curve and the ratios of the two galvanometer readings as ordinates. The method of taking the readings was as follows:

Starting with no difference of path, readings were taken in order through the different maxima and minima of the curve. Near the maxima and minima the readings were taken very close together, in order definitely to determine these points. At a maximum or minimum, two readings were taken every few millimeters on both sides and around these parts of the curve. In this way the curve was gone over three times, and at least six readings were taken at every point, the mean of these readings being the value plotted. This was done to eliminate as far as possible the influence of irregularities in the action of the vibrator and galvanometer, and in external conditions. At intermediate points of the curve, three or four readings were taken at intervals of one or two centimeters. In this way the interference curves were obtained, and the positions of three maxima and four minima in each curve were determined.

In the case of the smaller spheres, only the wave-length of the fundamental vibration was measured; for it was thought that there would not be enough energy to make accurate measurement possible in the upper partial vibrations. In the larger vibrator the wave-lengths of the fundamental and two upper partials were sought. The wave-lengths as determined by the interference curves are given in Table V.

Non-Effect of Grating Space on λ. — It was not known whether the grating space exerted any influence on the wave-length. Two

series of measurements were therefore made to determine what this effect was. Curves 5 and 6, Fig. 8, show the results of this work. Only a portion of the interference curve was obtained in each case; for since the difference in grating space was taken between such wide limits, it was thought that a few points of the curve would show whether the grating space had any appreciable effect on the

TABLE V.

Large Vibrator.						Small Vibrator.	
Fundamental. Curve 1.		First Upper Partial. Curve 2.		Second Upper Partial. Curve 3.		Fundamental. Curve 4.	
1/4λ.	1/2λ.	1/4λ.	1/2λ.	1/4λ.	1/2λ.	1/4λ.	1/2λ.
8.25		4.85		3.40		5.00	
7.60	15.85	4.60	9.45	3.50	6.90	5.30	10.30
8.20	15.80	4.65	9.25	3.65	7.15	4.40	9.70
7.85	16.05	5.10	9.75	3.55	7.20	4.85	9.25
8.35	16.20	4.75	9.85	3.80	7.35	5.60	10.45
7.50	15.85	5.00	9.75	3.30	7.10	4.80	10.40
Mean	15.95		9.61		7.14		10.02
Mean error = 0.9%			2.2 %		1.6 %		4.4 %
Prob. error = 0.3%			0.8 %		0.7 %		1.6 %
$\lambda = 31.90$ cm.		$\lambda = 19.22$ cm.		$\lambda = 14.28$ cm.		$\lambda = 20.04$ cm.	

wave-length. The curves are very irregular, and the maxima and minima points at best can be only roughly decided upon. In curve 5, the grating space was 17 cm. and in curve 6, it was 6 cm. In both curves the thermo-junction had a length of 15.8 cm. Curve 5 gives a wave-length equal to 34.8 cm., and curve 6 gives one equal to 33.6 cm. Both of the wave-lengths measured from these curves are greater than the wave length of the fundamental vibration, and the difference between them and the fundamental is a little more than the outside limits of error. The deviation from the fundamental may be accounted for by the fact that there is more scattered radiation when the grating space is not adjusted for equal reflection and transmission, consequently the maxima and minima are less distinct, as will be seen from curves 5 and 6, and λ is harder to measure.

If the grating space had exerted any decided influence on the wave length, we might have expected that the wave-length determined by curve 6 would have been smaller than the fundamental, which

had a grating space of 12 cm., and that the wave-length determined by curve 5 would have been greater. As these effects were not found it appears that the grating space alone has no appreciable effect on the wave-length measured.

Measurement of λ by a receiver not in resonance with the vibrator. — It was desired to determine the wave-length measured by a receiver whose dimensions were between those of the receiver for the fundamental and the receiver for the first upper partial. The experiment was performed with a resonator 118 mm. long, and an interference curve, No. 7, was plotted. The wave-length taken from this curve was equal to 27.4 cm. This value differs very widely from the wave-length of the fundamental and still more widely from that of the first harmonic. The following question now arises. Is this divergence due to the shorter length of the receiver and therefore does it tend to confirm the theory that the receiver determines the length of the wave measured, or does it show that there are waves present other than the fundamental and its series of upper partials? These experiments are not complete enough to answer this question conclusively. A study of the energy curves will show that in several cases the principal maximum is very irregular and this would seem to indicate that there is, mixed up with the fundamental, other vibrations of nearly its own period. Some of the maxima on the interference curves show irregularities which would indicate the same. In curve 7, Fig. 4, appear supplementary maxima at 148 and 131 on the scale, and the wave-length measured with this receiver very nearly corresponds to the latter vibration, supposing for the time that wave-length bears a constant ratio to receiver-length. This length of receiver was chosen entirely at random, and it is unfortunate that this precise length was taken, for under the circumstances it is not possible to answer definitely the foregoing question.

It was thought at first that with the interferometer it would be possible to measure absolutely the length of electric vibrations if some receiver could be found which had no definite period of its own. G. F. Hull[1] used a coherer for a receiver in his work with the interferometer and he found that even this receiver influenced to some extent the wave-length measured. The electric vibration

emitted by such an exciter as was used here is heavily damped, and though the damping as shown by the interference curves is less than theory suggests,[1] yet in such a vibration the first pulse is relatively more effective than the waves which follow it.

When the first pulse of the damped wave train strikes the receiver, the resonator is set in vibration and it continues to vibrate with its own period. This vibration of the receiver is stopped only when the mirrors of the interferometer are in such a position as to cause the waves to arrive in a phase opposite to the vibration of the receiver. Thus there is measured the wave-length of the vibrator as modified by the receiver and not the absolute length of the wave sent out by the vibrator.

Relation Between Resonator-length and Wave-length. — It is interesting to note the dependence of the resonator-length upon the wave-length, as shown from these experiments, and to determine whether in this respect the results of these experiments agree with the values found by other investigators. Poincaré[2] gives 2 as the ratio of wave-length to resonator-length. Macdonald[3] theoretically derives the formula $\lambda = Kl$, where λ is the wave-length, l the resonator-length, and K a constant. For the fundamental vibration, K in the formula $\lambda = Kl$, is equal to 2.53. This value has been proved to hold for circular receivers. Below is a table of values for K computed from these experiments:

	l	λ	$k = \frac{\lambda}{l}$
Small spheres, fundamental.	8.16	20.04	2.46
Large " "	15.8	31.90	2.02
first harmonic.	7.9	19.22	2.43
second "	5.6	14.28	2.55

It is evident that these values do not agree with the value given by Poincaré, but they agree approximately with the value given by Macdonald, except in the case of the fundamental for the larger spheres. Here K is equal to 2.02, while Macdonald's theory gives

[1] G. F. Hull, l. c.

[2] Poincaré, "Les Oscillations Electriques."

[3] Macdonald, "Elective Waves," Adams Prize Essay in the Univ. of Cambridge, p. 111.

2.53. It looks as though the vibration between the small spheres and the large ones affects the fundamental in the case of this vibrator. But the harmonics may not be so affected and their λ's fall in with Macdonald's value. The same reasoning may account for the ragged energy curves in the region of the fundamental.

Basing the calculation on these experiments, it would seem that for a linear receiver the formula $\lambda = K(l + a)$, where λ is the wave-length, l the resonator-length, and K and a are constants, is more nearly correct than the formula $\lambda = Kl$. Using $K = 1.75$ and $a = 2.67$, the formula gives values for the different wave-lengths approximately equal to the experimental values. This can best be seen from a table.

Given $\lambda = K(l + a)$. $K = 1.75$. $a = 2.67$.

	Expt. Value.	Computed Value.
Small spheres, fundamental.	20.0	19.0
Large " "	31.9	32.3
first harmonic.	19.2	18.5
second "	14.3	14.47

Fundamental and Upper Partials. — A study of the table will show that, although the fundamental resonator for the larger spheres is approximately twice the length of the fundamental resonator for the smaller spheres, the wave-lengths do not have this simple relation. Nor do the wave-lengths of the upper partials of the larger spheres bear the same relation to the fundamental that the receivers for the upper partials bear to the receiver of the fundamental. But the wave-length of the fundamental of the smaller spheres is nearly equal to the wave-length of the first upper partial of the larger spheres. The receivers used to measure the wave-lengths of the vibrations were of the same length as the receivers found by the energy curves to be in resonance with the fundamental and upper partials of the exciter. These lengths have been said to bear nearly the same relation to each other as the upper partials bear to the fundamental in the vibration of a stretched string. The fact that the wave-lengths measured do not have this submultiple relation does not prove that the upper partial vibrations are not present. It is evident that this part of the experiment is not conclusive, but that

it bears out the inference deduced in Part II., that a Righi vibrator sends out a fundamental and at least two upper partials.

Corrections Which May Be Applied to the Inference Curve. — If one of the mirrors of the interferometer is removed, it is found that the intensity of radiation falling upon the receiver is not a constant, as the position of the other mirror is changed. Indeed the intensity does not even decrease uniformly as the mirror is moved away from the separating surface, *i. e.*, as the path is increased, but there is a rise and fall in the intensity showing the influence of standing waves. The interference curve is therefore affected by those standing waves and also by scattered radiation. But the effects are small and do not alter the main argument.

IV. Conclusion.

The points brought out by these experiments are these:

1. That the measurement of energy with a linear receiver of definite length showed the existance of a fundamental and upper partials.

2. That the relation of the receiver-lengths for the fundamental and the successive upper partials stand in the relation 1, 2, 3.

3. That the wave-length and receiver-length are connected by the relation indicated in the formula $\lambda = K(l + a)$.

4. That the interference curves show that the damping in a Righi vibrator is less than the theoretical value computed by Thomson for the radiation from a single sphere.

5. That the grating space of the separating surface does not affect the wave-length measured.

6. The character of the emission of a Righi vibrator, as shown by the foregoing experiments, may be accounted for by a modified statement of Sarasin and de la Rive's hypothesis, but is more rationally explained, in the opinion of the writers, on the basis of the hypothesis of Bjerkness and Poincaré. The results of the present experiments are, however, too limited in extent and too uncertain to give conclusive evidence in favor of either view.

A portion of this paper was submitted by the writers to the faculty of Dartmouth College as a thesis for the degree of Master of Arts.

These experiments were performed in the Wilder Physical Laboratory in Dartmouth College under the direction of Prof. E. F. Nichols and Prof. G. F. Hull, to whom we are much indebted for many valuable suggestions both in the construction of apparatus and in the methods employed in the experiment.

ON THE THEORY OF THE ELECTROLYTIC RECTIFIER.

By S. R. Cook.

WHEN aluminum, with a free metallic surface, is the anode of an electrolytic cell which has dilute sulphuric acid, aluminum sulphate, potassium aluminum sulphate (alum), ammonium aluminum sulphate, potassium cyanide, or potassium ferrocyanide for the electrolyte, there is quickly introduced into the electrolytic cell a condition which produces a very high apparent resistance, so long as the voltage is not above a certain critical value. If, however, the aluminum is made the kathode, in any of the above solutions, and carbon or platinum the anode, the cell becomes a very good electrolytic conductor. This anomalous action of the aluminum anode in an electrolytic cell, in which oxygen is one of the products of electrolysis, was observed in 1857 by Buff,[1] while making more detailed observation on Wheatstone's[2] experiments for determining the position of aluminum in the voltaic series. Buff found that when dilute sulphuric acid was the electrolyte, a dark skin appeared on the surface of the aluminum anode and that the resistance was very much greater than when the aluminum was the kathode and either carbon or platinum was the anode.

In 1869, Thomson's electrometer being accessible for the measurement of potential, independent of resistance; Tait[3] while measuring the polarization of several cells determined the polarization of aluminum in dilute sulphuric acid. He applied an electromotive force of six Grove cells (10.44 Daniels) and with the Thomson electrometer found a counter electromotive force of 5.20 Daniels. No explanation was given for this very high counter E.M.F. and until very recently no explanation has been offered for the very high apparent resistance of the aluminum anode.

[1] Buff, Liebig's Annalen, CII., p. 169, 1857.
[2] Phil. Mag. (4), X., p. 143, 1854.
[3] Phil. Mag. (4), XXXVIII., p. 243, 1869.

In 1877 Beetz[1] investigated the dark skin observed by Buff and concluded that it was the normal oxide or hydroxide. While Lawrie,[2] from the effect of amalgamation on the electrochemical behavior of aluminum, came to the conclusion that the action of the aluminum anode was due to an oxide or suboxide. Oberbeck[3] and Streintz[4] considered the film formed on the aluminum anode a non-conductor and suggested that the aluminum, non-conducting film, and solution formed a condenser. They found that this cell had a measurable capacity, and a condenser consisting of two aluminum plates in dilute sulphuric acid has been described by Haagn.[5] In 1897 it was shown by Pollak[6] and independently by Gratz[7] that a cell composed of aluminum and carbon or aluminum and platinum with dilute sulphuric acid as the electrolyte could be employed to rectify an alternating current. This discovery brought the cell into practical importance and in 1898 the efficiency of this electrolytic rectifier was investigated by Wilson.[8]

Norden[9] investigating the chemical composition of the film on the aluminum anode, came to the conclusion that with dilute sulphuric acid as the electrolyte the film was composed of the normal aluminum hydroxide $Al_2(OH)_6$ with some aluminum sulphate. Wilson has shown that this film of oxide or hydroxide formed on the aluminum anode has a very high resistance; having observed values up to 10,000 ohms. Norden[10] attempted an explanation of the cause of the high anodic resistance of aluminum. From observations he found that the resistance of the resting cell was much less than the active cell and also that the film (supposed aluminum hydroxide) was acted upon by the solution and he concluded that if the film was weakened by the dissolution action of

[1] Pogg. Annalen, Vol. CXXVII., p. 45; Vol. CLVI., p. 464.
[2] Phil. Mag. (5), XXII., p. 213, 1886.
[3] Wied. Annalen, XIX., p. 625, 1883.
[4] Wied. Annalen, XXXII., p. 116, 1887; XXXIV., p. 751, 1888.
[5] Zeit. für Electrochemie, III., p. 470, 1896-1897.
[6] Compt. Rend., CXXIV., p. 1443, 1897.
[7] Weid. Annalen, LXII., p. 323, 1879.
[8] Electrical Review (London), p. 371, 1898; Pro. Royal Society, Vol. LXIII., p. 329, 1898.
[9] Zeit. für Electrochemie VI., pp. 159, 188, 1899–1900.
[10] Elec. World and Eng., Vol. 38, p. 681, Oct. 26, 1901.

the liquid bathing it while resting, the same action would take place in the active cell and the current would break through these weakened parts. Burgess and Hambuecher,[1] following the same general theory, tried to establish the existence of these small areas of disruption by removing the aluminum anode and depositing copper from a solution of copper sulphate in the openings made by the dissolution of the film. This theory, namely, that the high apparent resistance of the cell, when aluminum is the anode and low resistance when aluminum is the kathode, is due to the high ohmic resistance of the film which by disruption or dissolution action allows the current to flow through unterrupted in one direction and closes up and almost completely prevents the passage of the current in the other direction, will be discussed later in connection with the data here presented.

Dr. Guthe[2] in a paper read before the American Association for the Advancement of Science, at its Pittsburg meeting, advanced another theory for the explanation of the resistance of the aluminum anode. From experiments performed he concluded that the resistance was due to a film of gas, probably oxygen, at the anode, which, when the current was reversed, united with hydrogen or was dissolved in the solution. This theory will be reverted to again after the presentation of the data.

Taylor and Inglis in the Philosophical Magazine of March, 1903, have also suggested a theory of the aluminum anode. They have shown that by adding salts, containing negative ions, which would normally dissolve the anode, to the dilute sulphuric acid solution, the high resistance at the aluminum anode was prevented or destroyed. The theory advanced is that the high resistance is due to the property of the film of hydroxide to allow all ions except the SO_4 ions to pass through.

In view of the fact that Tait had, by a method independent of the resistance, obtained a counter electromotive force greater than is usual in electrolytic cells, and in view of the fact that the theories heretofore advanced to explain the apparent high resistance of the aluminum anode are not without objection, it seemed possible that,

[1] Trans. Amer. Elec. Chemical Soc., Vol. I., p. 147, 1902.
[2] PHYSICAL REVIEW, Vol. XV., p. 327, 1903.

by a closer investigation of the value of the counter electromotive force, some further explanation of the high anodic resistance of the aluminum cell might reveal itself.

2. *Apparatus.*—The apparatus for the investigation of the counter electromotive force of the electrolytic rectifier consisted of an accumulator of twenty-eight cells, the electrolytic rectifier, which consisted of a cell with an aluminum plate, 7.5 x 10.2 cm., and a carbon plate of the same cross-sectional area, in a solution of potassium aluminum sulphate, a Weston ammeter, milliammeter and voltmeter, a relay and several keys and pole-changers arranged as in Fig. 1.

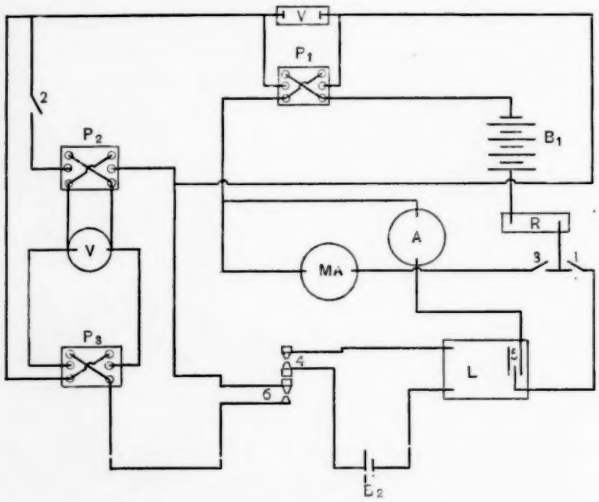

Fig. 1. Apparatus Diagram.

In the diagram V is the electrolytic rectifier, B_1 the accumulator, R a rheostat, L the relay, A and MA are the ammeter and milliammeter respectively, and V is the voltmeter. The pole-changers are designated by p_1, p_2, etc., and the keys by the numbers 1, 2, 3, etc., No. 5 being the break key on the relay, which was operated by the auxiliary battery B_2.

3. *The Method of Making the Observations.*—All connections having been made the plates were set at a distance of about 2 cm. and the electrolyzing current made by closing keys 1 and 5. The electrolyzing current now flows through the relay, the ammeter and the

electrolytic cell. The applied electromotive force is measured by closing key 2, thus putting the voltmeter across the terminals of the cell. The current flowing through the cell, when small, was measured by opening key 1 and closing key 3, thus putting the milliammeter in the circuit. When key 3 was opened key 1 was closed and remained closed throughout the remaining time for each observation. In order to measure the counter electromotive force, key 2 being open, key 4 was closed. The action of the relay opened key 5 and broke the electrolyzing current and the next moment the closing of key 6 put the voltmeter across the poles of the cell.

4. *Errors of the Observations.* — When the voltmeter was thus placed across the terminals of the electrolytic rectifier, after the electrolyzing current had been broken, the indicator of the voltmeter would quickly swing up to a position depending on the applied electromotive force and the temperature of the cell, and would fall back more slowly to a comparatively small value.

It will be evident that the method was not one of great precision, there being at least two errors which could not be accurately determined. First the momentum of the moving system of the voltmeter would tend to carry the pointer beyond the true reading, by an amount depending upon the voltage to be measured. It was found by repeated observation, by quickly applying a constant voltage for a short time to the voltmeter that if the voltage applied was 14 volts, the pointer would swing to a position indicating 15 volts and that if the applied voltage was 30 volts the pointer would be carried to a position indicating 32 volts, showing that the momentum of the system caused an error of about six and two thirds per cent. This, however, depended on the time during which the electromotive force was applied. The percentage here given is that for infinite time. Secondly there exists an error due to the decrease of the counter electromotive force, during the interval between breaking the electrolyzing current and making the voltmeter circuit. This interval was short, but as the polarization diminished very rapidly at first, the error may have been several per cent. We may also include in this error the error due to the time required for the pointer of the voltmeter to swing up to its maximum reading. The value of this second error could not be determined with the ap-

paratus used, and no correction has been made for it. The data in the tables are corrected for the error due to momentum. It will be observed that the second error, not corrected for, decreases the true value of the counter E.M.F.; accordingly the values recorded are not so great as the true values.

5. *Measurements of the Counter E.M.F.* — In the following tables are given a series of sets of measurements of the counter electromotive force of the electrolytic rectifier, at various temperatures and conditions of the cell. Four represesentative sets at temperatures 1°, 23°, 48° and 58°, respectively with aluminum as anode and one at 1° with aluminum as kathode are recorded. These determinations were several times repeated with results agreeing substantially with those recorded.

Measurements of applied E.M.F. current and counter E.M.F. at 1° with a well-formed aluminum anode and a carbon kathode are given in Table I.

TABLE I.

Temperature 1°.

Applied E.M.F.	Amperes.	Counter E.M.F.	Applied E.M.F.	Amperes.	Counter E.M.F.
2.1	.0002	1.9	28.0	.0040	24.5
4.5	.0003	3.3	30.0	.0045	26.2
6.7	.0005	6.0	32.0	.0075	26.8
9.0	.0007	7.6	34.0	.0160 ?	27.6
11.2	.0010	9.8	36.4	.0165	28.8
13.5	.0015	11.6	38.7	.0220	30.0
15.5	.0020	13.5	41.0	.0250	31.0
17.4	.0025	15.0	43.2	.0275	31.2
19.5	.0025	17.0	45.0	.0460	31.0
21.3	.0027	18.8	47.2	.1100	29.0
23.4	.0031	20.7	49.3	.1800	27.0
25.7	.0036	22.6	51.0	.5000	19.0

The data from this table are exhibited in the curve in Fig. 2 so far as 30 volts. Curve *I* exhibits the applied E.M.F. and current. Curve *II* exhibits the counter E.M.F. and current. Curve *III* exhibits the electromotive force from Ohm's law, assuming the resistance to be constant at 2 ohms, the value obtained from a series on measurements by Kohlrausch's method.

Table II. gives the data for the same cell under the same conditions with aluminum as the kathode.

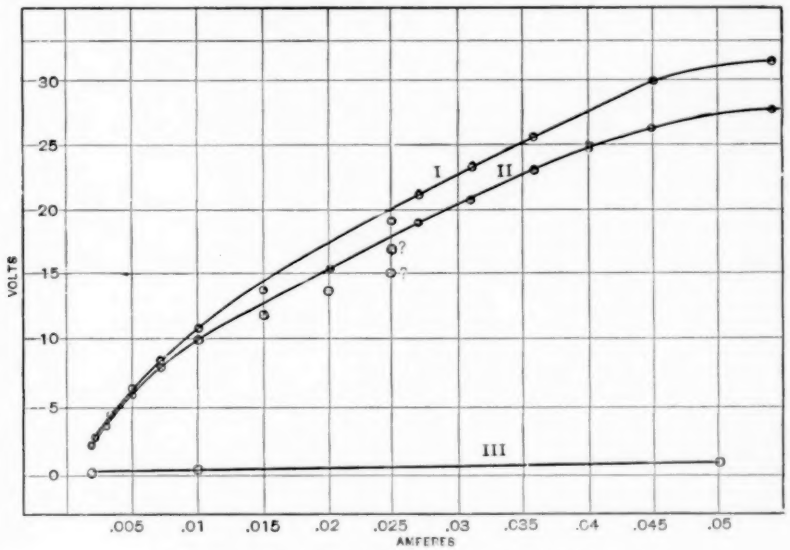

Fig. 2. Applied Counter and Reversed E.M.F.

TABLE II.

Temperature 1°.

Applied E.M.F.	Amperes.	Counter E.M.F.	Applied E.M.F.	Amperes.	Counter E.M.F.
1.07	.020	0.4	1.5	.150	0.8
1.2	.020	0.4	2.0	.300	1.25
1.3	.050	0.6	2.5	.500	1.5

Tables III., IV. and V. give applied and counter E.M.F. of the same cell for temperatures 23°, 48° and 58° respectively.

TABLE III.

Temperature 23°.

Applied E.M.F.	Amperes.	Counter E.M.F.	Applied E.M.F.	Amperes.	Counter E.M.F.
2.0	.0002	1.2	19.6	.0046	16.0
4.4	.0009	3.0	21.0	.0060	17.0
6.4	.0012	5.0	23.0	.0110	19.0
8.5	.0015	7.0	25.2	.0160	20.0
10.2	.0019	9.0	27.0	.0320	21.0
13.0	.0022	11.0	29.0	.0900	21.0
15.2	.0025	12.0	32.0	.2250	21.0
16.7	.0035	14.0	32.2	1.2000	19.0

TABLE IV.

Temperature 48°.

Applied E.M.F.	Amperes.	Counter E.M.F.	Applied E.M.F.	Amperes.	Counter E M.F.
2.1	.0002	1.2	20.0	.0120	17.0
4.4	.0020	3.0	22.2	.0700	16.0
6.8	.0030	4.5	24.3	.1600	16.0
9.0	.0040	7.0	26.2	.2100	16.5
11.3	.0050	9.0	28.5	.2250	18.0
13.8	.0065	10.5	31.0	.2500	19.0
16.0	.0080	12.5	33.0	.3100	19.8
18.2	.0115	15.5	34.7	.6000	19.0

TABLE V.

Temperature 58°.

Applied E.M.F.	Amperes.	Counter E.M.F.	Applied E.M.F.	Amperes.	Counter E.M.F.
2.0	.075	0.5	19.4	.280	11.3
4.2	.120	2.0	21.2	.340	13.0
6.4	.140	3.8	23.2	.425	14.0
8.5	.160	5.0	26.2	.460	15.0
11.0	.185	6.5	28.2	.550	16.5
13.0	.200	8.0	29.8	.860	17.0
15.0	.250	9.0	31.0	1.300	16.0
17.5	.250	10.0			

The data from the respective Tables I., II., III. and V. are exhibited in Fig. 3.

Curves *I* and *I'* exhibit the relation of the applied and counter electromotive forces to the current, the temperature of the cell being 1°.

Curves *II* and *II'*, and *III* and *III'* exhibit similar data from Tables III. and V. respectively at temperature 23° and 58°, and curve *IV* exhibits the data from Table II. giving the applied E.M.F., when the aluminum is the kathode, at a temperature of 1°.

The effect of temperature upon the apparent resistance of the aluminum anode is very marked. At temperatures not much above 55° the very rapid increase in current at a certain critical electromotive force is hardly perceptible, while at temperature below 50° the position of the critical value of the electromotive force is

clearly defined. The value of the critical electromotive force decreasing as the temperature increases at the rate approximately of 1 volt per degree between 1° and 23°.

6. *Discussion of Data.* — A comparison of the applied and counter electromotive forces in Tables I., III., IV. and V. and their corresponding curves, Figs. 2 and 3, show that eighty-five to ninety-five per cent. of the apparent resistance is accounted for by the counter electromotive force and it only remains to explain the cause of this very high counter electromotive force and account for the breaking down of the high apparent resistance at a comparatively high

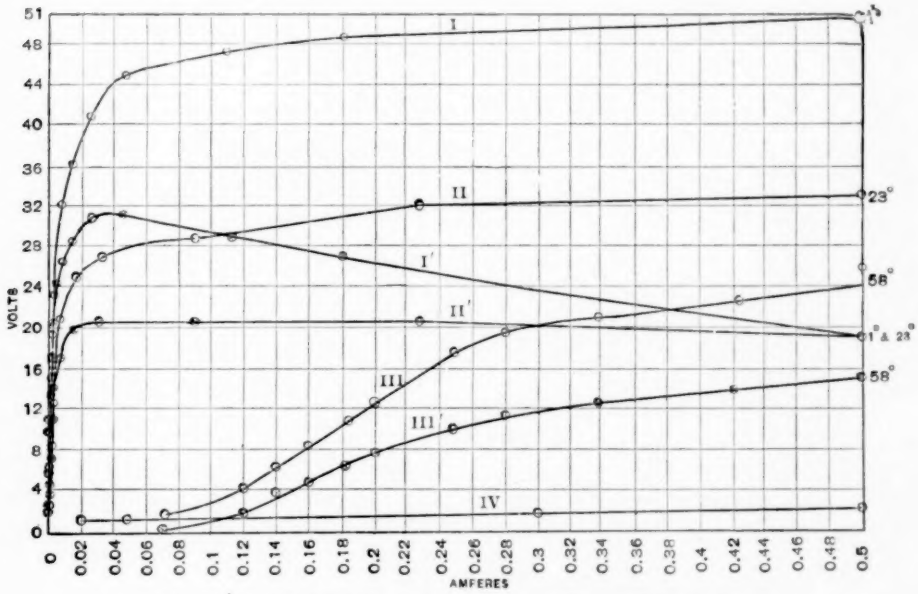

Fig. 3. Applied and Counter E.M.F. for Different Temperatures.

electrical pressure. So long as the applied electromotive force remains below a certain critical value depending on temperature, a uniform whitish film of an oxygen compound of aluminum is formed over the surface of the aluminum anode. This film can be shown to be extremely hard, compact, non-crystalline and apparently insoluble in the electrolyte. The ohmic resistance of the film has also been shown to be very high.

When, however, the applied electrical pressure is greater than a certain critical value this film of alumina changes from a white

non-crystalline substance to a dark crystalline substance. These dark crystalline formations occur in parts of the plate only and they always begin to form at those parts where the oxygen is found in the greatest quantities. This dark crystalline formation has very much the appearance of corrundum or emery. If a plate is removed at this stage and carefully examined it will be found that the dark parts are elevated and rough to the touch. When examined with a microscope, of forty diameters magnifying power, the crystalline formation can be easily seen and frequently not only dark corundum-like crystals but crystals of brilliant colors could be easily detected. On a very superficial examination, these brilliantly colored crystals have the appearance of being small crystals of ruby and sapphire.

The formation of crystals exposes the metallic surface of the aluminum plate to the action of the electrolyte and allows the anions to discharge to the anode increasing very rapidly the current, while the continued formation of the crystals, so long as the electrical pressure is greater than the critical value, continues to expose fresh surfaces of the metallic aluminum to the action of the anions. When the critical value of the applied electromotive force has been reached it will be observed that the counter electromotive force decreases and the current greatly increases as the applied electromotive force is increased. That is, as soon as the anions can give up their charge to the metallic aluminum the counter electromotive force decreases. The very high counter electromotive force then is due to the presence of a large number of charged ions around the aluminum plate. These anions (possibly SO_4) are prevented from reaching the metallic conductor by the whitish film of alumina that has been formed on the anode. A further evidence of the presence of this wall of charged ions is given, if a conductor is brought near the anode, when there is a high counter electromotive force, a spark discharge will occur in the solution between the conductor and the layer of charged ions and at the time of the discharge the current greatly increases. It is not believed that this momentary increase of current is due to any rupture of the film but simply to the renewing of the layer of anions which had lost their ionic condition by discharging to the conductor.

Still another experiment shows the existence of this layer of charged ions. The electrolytic cell was under an electrical pressure of 26 volts with a counter electromotive force of 17.5 volts, giving .07 ampere of current. Air bubbles were forced into the solution and caused to pass over the surface of the aluminum anode. The current rapidly increased to 0.35 ampere and fell again to .07 ampere, when the bubbles ceased. The pointer of the milliammeter responded very quickly to the passage of a large bubble over the surface of the anode but it was not possible to measure the decrease of the counter electromotive force under these conditions. The temporary increase of the current may be explained by the temporary destruction, in part, of the concentration series, by the passage of the air bubbles over the plates.

If the electrical pressure is maintained for some time above the critical pressure the film of alumina not only forms crystals but is dissolved by the solution, forming depressions in the plate where the crystallization had produced elevation. This dissolving of the dark crystalline formation was observed by Norden and was made the basis of his theory of the aluminum anode. I think, however, that it is very doubtful that the white alumina is dissolved by the solution even by long standing. The crystalline formation may however either be dissolved by the solution or it may separate from the plate and fall into the solution in the granular form. By maintaining the voltage above its critical value for several hours an aluminum anode that had been formed with the dark crystalline formation, was largely dissolved by the electrolyte. This dissolution of the crystalline formation does not however offer an explanation of the anodic phenomenon.

The explanation given by Burgess and Hambuechen is also based upon the idea of a non-conducting film which changes its properties rapidly when the current is reversed. As already stated when the aluminum is the anode oxygen is the secondary product of the discharge anion. The oxygen unites with the aluminum, forming a film over the surface of the anode. When aluminum is the kathode hydrogen is the secondary product of the kation and is set free. The kation also discharges to the metallic surface of the aluminum. If the film is already formed hydrogen gas is formed between the

metallic surface and the film, breaking away small areas of the film. It was probably these small areas that Burgess and Hambuechen considered the valves through which the current passed and into which they deposited copper.

When aluminum is the anode and the potential is less than the critical value, it has been shown that there is formed a film of alumina on the surface of the aluminum, which prevents the anions from discharging to the metallic surface of the anode, thus causing the formation of a layer of charged ions around the plates which produces a high counter electromotive force. This high counter electromotive force decreases the effective potential and manifests itself as a high apparent resistance.

7. *Determination of the Rate of Increase of the anions Around the Anode.*— In accordance with the theory that the ions would discharge their electricity when the free metallic surface was exposed by the crystallization of the aluminum; it became important to know whether a free metallic aluminum surface would conduct an electrical current as freely when it was the anode as when it was the kathode. In order to determine the conductivity of a free metallic surface of aluminum, a plate was freed from all oxide film by scraping with a sharp tool after the application of turpentine, thus giving a very bright metallic surface. The plate was then made the anode of an electrolytic rectifier with carbon as kathode and the data in the following table were obtained, the applied E.M.F. being constant at 26 volts.

TABLE IV.

Time Hr.	Min.	Sec.	Amperes.	Counter E.M.F.	Time Hr.	Min.	Sec.	Amperes.	Counter E.M.F.
1	42	30	9.000	0.2	1	47	00	.130	16.0
1	42	35	1.500	0.5	1	48	00	.135	16.5
1	42	45	.300	3.0	1	50	00	.130	17.0
1	43	45	.250	7.0	1	55	00	.120	17.0
1	44	30	.190	15.0	2	00	00	.105	17.0
1	45	30	.150	15.0	2	10	00	.090	17.5
1	46	30	.145	16.0	2	50	00	.070	17.5

The curves exhibiting the relation between the time and the current, and the time and the counter E.M.F., are given in Fig. 4. Curve *I* shows the very rapid fall of the current from 9 amperes to

.07 ampere. Curve *II* shows the rapid increase of the counter electromotive force, and curve *III* exhibits the constant current when aluminum was the kathode. Although the value of the current as first measured when aluminum was anode is not so great as its constant value when aluminum was the kathode, the very close approximation to the constant kathodic value is a strong argument in favor of the theory that the first anions (SO_4) discharge their electricity when in contact with the metallic aluminum and that it is the formation of the negative ions in a concentration series or the presence of the free oxygen, evolved from the union of SO_4 with H_2O; in process of union with the aluminum that produces the high counter electromotive force which reduces the current to aminimum.

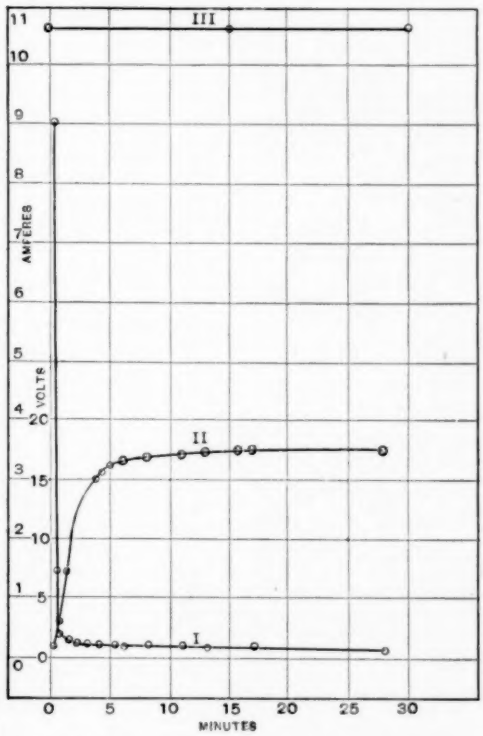

Fig. 4. The rate of Formation of an aluminum Anode and the Development of the Counter E.M.F.

8. *Is the Oxygen Added Directly to the Aluminium?* — An effort was made to answer this question by the following experiments:

A large H cell was constructed. Each leg of the cell was fitted with a carefully weighed aluminum electrode, a thermometer, and a graduated tube for receiving and measuring the gas given off. The cell was filled with a solution of potassium aluminum sulphate, placed in a constant temperature bath and a current passed through until a measured quantity of hydrogen was liberated. The electrodes were then removed, weighed and the gain or loss determined. Four independent experiments were performed and the following observations and notes were made:

First Experiment. — The aluminum electrode exposed a clean metallic surface to the electrolyte. The temperature of the cell was 15°.

Results from first experiment :

Weight of anode before the experiment,	24.3915 grams.
Weight of anode after the experiment,	24.3997 grams.
Gain in weight of anode during experiment,	.0082 grams.
Weight of kathode before the experiment,	23.9955 grams.
Weight of kathode after the experiment,	23.9949 grams.
Loss in weight of kathode,	.0006 grams.
Hydrogen liberated at kathode,	59 c.c.
Oxygen liberated at anode,	0 c.c.
Amount of oxygen that should have been liberated,	.0415 grams.

On the theory that the oxygen is added directly to the anode this experiment should have given an increase in the weight of the anode of .0415 gram, while it gave only .0082 grams of oxygen or about one fifth the amount required. However, this experiment shows that the oxygen does not remain in the gaseous form and must be accounted for either by assuming that it forms a soluble compound with the anode, and is then dissolved by the electrolyte, or that it forms an insoluble compound with the anode, part of the anode being dissolved by the electrolyte to account for the discrepancy. Norden[1] concluded that the electrolyte acts chemically on the anode at ordinary temperature, and in my own work I have been successful in dissolving a large part of an aluminum anode after it had been formed with the dark formation. In order to account for the loss by dissolution the experiment was repeated with the cell in an ice-bath.

EXPERIMENTS 2 AND 3 WITH THE H CELL.

The H cell arranged as in the former experiment was packed in ice and allowed to reach a temperature of 1°. At first an electromotive force of 33 volts was applied and the amperage during the three hours and twenty minutes fell from 0.105 ampere to .008 ampere. The electrical pressure was then increased to 52 volts and the amperage soon became constant at .07 ampere. In three hours 70 c.c. of hydrogen was liberated at the kathode. No gas was liberated at the anode.

[1] L. c.

The anode showed a gain during the experiment of .0318 grams and the kathode a loss of .0045 grams. If all the oxygen set free from the electrolyte had been added to the anode, and there had been no dissolution of the anode during the experiment there should have been an increase of .0501 grams, showing a discrepancy of .0184 grams; that is, about thirty-six per cent.

The experiment was again repeated under the same conditions and the anode showed, for 55 c.c. of hydrogen liberated, a gain of .0243 instead of .0372 grams, a discrepancy of .0149 or forty per cent.

It was here observed that some of the oxygen collected at the upper end of the anode and that most of the formation was at this place. It was also observed that the dark formation showed signs of having been dissolved by the electrolyte. To prevent this dissolution of the formed anode a band of india rubber was fitted over that portion of the anode which passed through the surface of the solution, and the experiment was again repeated at a temperature of 0°.

For the fourth experiment the following results were noted: 25 c.c. of hydrogen was liberated. The increase in weight of the anode was .0237 gram. The weight required to account for 25 c.c. of hydrogen is .01792 gram, the excess of weight at the anode being .00583 gram.

Although these experiments have by no means been conclusive in showing that the oxygen is added directly to the aluminum as Al_2O_3, they nevertheless show that the oxygen does not remain as a gaseous film around the anode, producing an ohmic resistance, and they also show that the oxygen is added to the aluminum as a chemical compound; either, with Norden, as the normal aluminum hydroxide, $Al_2(OH)_6$, or as I believe more probable as aluminum oxide, Al_2O_3, with water of crystallization in that part of the oxide which crystallizes. It is also possible, according to Norden's analysis, that some of the sulphate is added to the solid formation of the aluminum anode. The problem of the exact composition of the formation on the aluminum anode at the different stages of its formation is one of great interest and I believe will merit the most careful investigation.

SUMMARY OF RESULTS AND CONCLUSIONS.

1. I believe the foregoing experiments have been conclusive in showing that the apparent resistance of the aluminum anode in potassium aluminum sulphate is not an ohmic resistance but a resistance of transition of the ions, primary or secondary, and that this resistance of transition manifests itself in a counter electromotive force. The formation of the film of alumina which is a very poor conductor of electricity on the surface of the aluminum anode prevents the anions from reaching a conducting surface and thus discharging. The anions, therefore, become massed around the positive plate in a layer of highly charged radicals (SO_4) or in a layer of highly charged atoms of oxygen which are in the act of entering into union with the metallic aluminum.

2. When the aluminum is the kathode hydrogen is the primary or secondary product at the aluminum surface and there is no chemical union at either the aluminum or carbon surfaces, if the aluminum surface is already covered with a film of alumina. The kation finds access to the metallic surface of the aluminum plate and hydrogen is set free between the film of alumina and the metallic aluminum, thus separating the two surfaces and exposing the metallic aluminum to further action of the kations.

3. It has been shown that when the electrical pressure is greater than its critical value the film becomes crystalline in structure and in crystallizing exposes free metallic surfaces to the action of the anions, allowing them to discharge to the metallic surface.

4. The value of the critical pressure and also the counter electromotive force depends upon the temperature. The critical electromotive force for 1° is approximately 47 volts and for 48° only 22 volts; the counter electromotive force increasing with decrease of temperature.

5. On account of the very high resistance of the film of alumina formed over the aluminum anode the anions do not give up their charge to this film, but must pass through to the metallic aluminum. When the anions have discharged the oxygen set free by secondary action of the radical SO_4 unites with the aluminum, thus increasing the film and decreasing the possibility of other anions reaching the metallic aluminum.

6. It has been shown that the high anodic resistance depends upon the temperature, and that at temperatures approaching the temperature at which aluminum decomposes water, *i. e.*, 100°, the high anodic resistance greatly decreases, thus showing that the anodic resistance depends upon the chemical conditions for the union of aluminum and oxygen.

7. The theory as here presented accounts for the following observed conditions and phenomena relative to the electrolytic rectifier. First, it explains the apparent high resistance of the aluminum anode and low resistance of the aluminum kathode. Second, it explains the critical electromotive force and the good conductivity of the anode above this critical pressure. Third, it explains the very great change of conductivity with change of temperature. Fourth, the increased weight of the anode is a direct result of the theory. Fifth, the good conductivity of the electrolyte when the aluminum has a metallic surface also follows from the theory.

In conclusion, it may be said that sufficient data have been obtained to explain many of the phenomena of the electrolytic rectifier; there are however still some interesting phenomena not explained; as, the exact composition of the film on the aluminum anode, the cause of the crystallization at and above the critical potential, the dissolution of the crystalline formation by the electrolyte, and the exact ionic condition that produces the high counter electromotive force. It is believed however that these problems are not beyond the possibility of being determined by careful investigation and it is the intention of the writer to investigate these conditions as soon as possible.

PHYSICAL LABORATORY, CASE SCHOOL OF APPLIED SCIENCE,
CLEVELAND, OHIO, July 22, 1903.

THE ELECTRICAL CONDUCTIVITY OF SOLUTIONS IN METHYL ALCOHOL IN THE NEIGHBORHOOD OF THEIR CRITICAL POINT. I.[1]

BY CHARLES A. KRAUS.

THE electrical conductivity of solutions has recently been applied to the study of the critical phenomenon.[2] It has been shown, not only, that solutions conduct beyond the critical point, but that the vapors of these solutions become conducting[3] before the critical point is reached. In the immediate vicinity of the critical point the temperature coefficient of the solution undergoes a change, resulting in a diminution of the coefficient. The dielectric constant, too, has been studied by Eversheim,[4] and follows in a general way the electrical conductivity of the solution.

The present paper treats mainly of two points in connection with the conductivity of solutions in the critical region; the change of the conductivity in the immediate neighborhood of the critical point, and the change of the conductivity with varying density of solvent fluid beyond the critical point.

One of the difficulties encountered in the work dealing with the conductivity at the critical point, has been the high value attained by the resistance. Hagenback[4] points out that the resistance of a solution in liquid sulphur dioxide increases a thousand times, in round numbers, in heating up to the critical point from ordinary temperatures. This circumstance leads to the use of complicated measuring apparatus and concentrated solutions, both of which are disadvantageous.

[1] The discussion of results is given in the concluding portion of this paper which is to appear in the following number of the REVIEW.—Ed.

[2] Franklin and Kraus, Amer. Chem. Jour., 24, p. 83, 1900. A. Hagenback, Phys. Zs., 1, p. 481, 1900; Ann. der Phys., 5, p. 276, 1901, and 8, p. 539, 1902. P. Eversheim, Ann. der Phys., 8, p. 539, 1902; Phys. Zs., June 15, 1903.

[3] A. Hagenback, l. c., Ann. der Phys., 5, p. 286.

[4] P. Eversheim, l. c.

[5] A. Hagenback, l. c., 5, p. 301.

Some years ago Franklin and Kraus[1] showed that for a large number of solutions in liquid ammonia the maxima of electrical conductivity lay within a comparatively narrow range of temperature about 100° below the critical point. Walden and Centnerszwer[2] have shown similar relations to hold true for solutions in sulphur dioxide. The same has long been known to hold true for certain water solutions. The regularity of the curves leads one to suspect that if one were able to find a solvent in which the conductivity maximum lay sufficiently near the critical point, the conductivity beyond the critical point would be considerable.

Now water solutions must possess maxima of conductivity that lie very near their critical point, if not beyond it.[3] The solvent power for glass makes the use of water as a solvent difficult in this instance. This has led the author to study the maxima of conductivity of the alcohols, compounds possessing many properties in common with water.

A solution of potassium iodide in ethyl alcohol reached its maximum of conductivity in the neighborhood of 100° C. It remained a conductor beyond the critical point, but the resistance attained considerable magnitude. In the immediate neighborhood of the critical point a considerable quantity of solute crystallized out on the walls of the tube, going into solution again as the temperature was somewhat increased.[4]

Solutions in methyl alcohol proved more promising. For a solution of potassium iodide, the maximum was found in the neighborhood of 160°. The conductivity beyond the critical point was found to be remarkably high. As will appear from the results given below, the conductivity just beyond the critical point has fallen to one tenth its maximum value, which is only a trifle less than one half its value at ordinary temperatures. Adding to its high conductivity, the ease of preparing and manipulating its solutions, methyl alcohol seems an ideal substance for the subject in hand. It possesses, however, some drawbacks, which, while not sufficient to affect mate-

[1] Franklin and Kraus, l. c.

[2] Walden and Centnerszwer, Zs. f. Phys. Chem., 39, p. 514, 1901–2.

[3] A. Hagenback, l. c., 5, 305; Arrhenius, Zs. f. Phys. Chem., 4, p. 96, 1889.

[4] This phenomenon may be of the nature of that investigated by Smits. Zs. f. Elec. Chem., no. 33, p. 663, Aug. 31, 1903.

rially the results aimed at in this paper, are yet of such a nature as to make exact measurements and comparisons difficult. Its high critical temperature makes it somewhat difficult to supply a constant temperature bath. The greatest drawback, however, is the tendency of alcohol to enter into reaction with any substance dissolved in it. Of a large number of substances dissolved in methyl alcohol, only the alcoholates and the bases were found to suffer a comparatively small change in conductivity on heating up. It was found, however, that the reaction was not as serious a matter as was anticipated. The reaction went on at a rapid rate and apparently went on to completion, for after once heating up, the conductivity remained constant thereafter. It appears that Hagenback [1] experienced some difficulty of this kind in sulphur dioxide. In some cases it was found that the critical point of alcohol solution was changed (lowered) on repeated heating. There also appeared to be some gas occluded on the electrodes. The tendency would naturally be for this gas to lower the critical temperature. With respect to the temperature measured from the critical point however, the conductivity remained constant, so that comparisons may still be made with regard to the critical point. This is probably the proper method of comparison any way, for a change in concentration of the solution will shift the critical point. The manner then in which this particular circumstance has affected the results is in giving to the temperatures a relative rather than an absolute value.

The nature of the reaction in the case of potassium iodide is doubtful. The odor obtained on opening the tube was suggestive of methyl iodide. The potassium would probably be present then as hydroxide or alcoholate. The maxima obtained in the case of alcoholate and hydroxide did not agree with those of the potassium iodide solution. The nature of the change must be left open for the present. Before exact results can be obtained at the critical point we must know the nature of the reactions occurring. It is hoped to take up this point subsequently, in a more extended study of the maxima of the alcohol solutions.

The measurements were carried out in a tube of approximately 1.5 mm. internal diameter and 2 mm. wall. The tubes had a

[1] A. Hagenback, l. c., 5, p. 295.

length of from 12 to 20 cm. The electrodes were from 1.5 to 2 cm. long and 1 mm. wide. They were held in relative position by small bits of glass. The connections through the glass tube were made with platinum of 0.04 cm. diameter. This size of wire is still sufficiently large to allow of ready manipulation, while it is so small that the glass is not appreciably weakened by its presence. To prepare a tube a piece of tubing of the dimensions given was selected. At one end this tube was drawn down so as to form a shoulder (*A*, Fig. 1). About 0.5 cm. beyond this shoulder the tube was drawn off. A small thick bulb (*B*) was blown on this end of the tube, and by means of a bit of glass two fine capillaries (*DD*) were drawn on this bulb. After cutting off the capillaries near the bulb, the electrodes (*C*) were introduced, the wires projecting each through one of the capillary tubes. The tube was now heated in the blow-pipe flame, taking care to heat the glass rather than the platinum wires. The bulb thickened and assumed a tubular form of considerable uniformity. The object of this operation was to seal the electrodes into the tube with a minimum thickening of the glass, *i. e.*, the whole tube, end and wall, were to be of as uniform dimensions as possible. While the tube was still in the flame the end was drawn out by pulling gently on the platinum wires until the electrodes rested on the shoulder (*A*) at the bottom of the tube. The tubes prepared in this way seemed to possess all the strength of the original glass tube. With tubes of the dimensions specified not a single explosion resulted. The tubes were tested by heating up twenty degrees or more, beyond the critical point.

Fig. 1.

The tube was plantinized and the resistance of the leads and the resistance capacity of the cell were determined. The open end of the tube was then drawn down into a long thick-walled tube of about 0.5 mm. internal diameter, and to make the total length of the tube shorter this tube was bent at an angle 60° to the rest of the tube. The volume of the tube and the volume per unit length were determined. The tube was finally washed with pure solvent and dried. After introducing the solution the tube was placed in a bath

of liquid ammonia, and the pressure was reduced as far as the vapor pressure of the alcohol would allow, when the tube was sealed. Before attaching the tube to the pump the capillary was drawn out very fine at one point in order to facilitate sealing off.

The heating was carried out in melted paraffine. The bath was constructed of a large beaker placed in a brass jacket with asbestos packing between. Glass-covered windows were left opposite each other for the purpose of observation. The heating was done electrically with a lamp-board resistance for control. This has many advantages over a flame for heating purposes. By means of hand regulation it was easy to keep a thermometer adjusted to a few hundredths of a degree. The heating coils were mounted on a glass frame and were distributed around the stirrer which was run by a small motor. The proper distribution of the coils around the stirrer added much to the constancy of the heating arrangement. While the temperature could be kept adjusted to 0.02° at any point in the bath, there was some variation in the different levels of the bath. For the space occupied by the tube, the variation did not exceed 0.05°, while the results justify the conclusion that for the electrode space the variation was considerably less than this. In the arrangement used the top of the bath was open to the air and a portion of the paraffine vaporized. This caused a cooling off of the bath and the top of the bath was the cooler. If this circumstance could be removed, this bath would give much better results than were possible with the arrangement used. For work that does not require the limit of accuracy the form of bath used can be recommended both for convenience and constancy. Perhaps it would not be amiss to add a few words in regard to the details of the preparation of the bath. A semicircular framework was made up of glass rods. On this framework the coils were stretched not only around the sides but also over the top and bottom. Two glass rods with their ends bent into closed rings of about .5 cm. diameter were sealed, one to the bottom of the frame, the other on longer supports attached to the top of the frame, and projecting over the beaker. A glass rod was chosen to fit the glass bearings and as many vanes were mounted on this rod as were desirable. The vanes were thus surrounded on all sides by coils except toward the

diameter of the semicircle. The tube was placed in this remaining semicircular space.

In order to read the volume of the liquid in the tube a milk glass scale was placed back of the tube and attached to it. The tube and scale were suspended in a carriage which could be put into, or taken out of, the bath without disturbing the rest of the apparatus. When accurate readings of volume were required the paraffiine bath had to be changed every other series. A weight and wire attached to one end of the scale and tube enabled the operator to invert the tube at will. The whole apparatus was placed under a hood and the tube was observed by looking through the window.

The conductivity was measured by means of a Kohlrausch bridge and telephone. The minimum was excellent except in the case of the highest resistances which were reached in only one series of measurements. But even in this case it was possible to set within a couple of millimeters. For measuring the temperatures two thermometers were used, one divided into tenths, the other divided into degrees. The one divided into tenths was used near the critical point. The temperatures were finally corrected by comparing them with a standard which was completely immersed while those to be calibrated were immersed as they were in the measurements. The conductivity of the glass comes into question in a measurement of the conductivity at high temperatures. The tubes empty did not indicate with the bridge a conductivity which could affect the results by more than a few per cent. with the highest resistances. With the smaller resistances the conductivity of the glass could not affect the results. The relative area of the conducting surface of glass to that of solution was about 1 to 20, so that with the solution twice as good a conductor as the glass the error would be a trifle over 2 per cent.

To change the quantity of solvent, keeping the quantity of solute constant, the tube was connected with a vessel containing sulphuric acid. The whole apparatus was then exhausted as far as the vapor pressure of the alcohol would allow. A small wire carrying a current was passed around the outside of the tube near the surface of the liquid. This heated the surface of the liquid and produced evaporation without danger of losing a portion of the solute. Liquid

could be introduced by cooling the tube in a bath of liquid ammonia, connecting with a reservoir of alcohol, and exhausting. It was found preferable, however, to change the quantity of solvent by evaporation.

CONSTANTS AND UNITS.

The resistance capacity of the tube was determined by means of a 0.1 *n*-solution of potassium chloride.[1] In the following tables the constant is given under K. Under $S \times 10^6$ are given the uncorrected values of the specific conductivity referred to Kohlrausch units[2]; the values actually appearing in the table are the products of the specific conductivities with 10^6.

V_t/V gives the ratio of the volume of the liquid at the temperature t to the total volume of the tube. Because of the unknown nature of the reaction taking place in the solution, the conductivities are not expressed in molecular values. The conductivities corrected for change in volume appear under $S \cdot V_t/V \times 10^6$. This is simply the product of the specific conductivity by the ratio of the volume of the liquid at temperature[3] t to the volume beyond the critical point. This method of correction has been adopted in preference to any other because in this case the actual specific conductivities appear above the critical point. The corrected value of the conductivity appears in all the curves.

To obtain the molecular conductivities the corrected conductivities need only be multiplied by a constant, which can be determined from the concentrations of solutions given and the volume of the tube.

How the correction affects the inclination of the curves will be discussed later. Under C appears the concentration of the solution in per cent. of solute. Whenever alcohol was extracted from a solution without removing solute, C refers to the concentration before the removal of the solute. The total volume of the tube at 240° is given under V. Under W appears the weight of the solution.

Unless otherwise stated the tubes were heated up to the critical point until no further change took place in the conductivity.

[1] Kohlrausch, Holborn and Diesselhorst, Wied. Ann., 64, p. 417, 1898; Kohlrausch and Holborn, "Das Leitungsvormögen der Electrolyte," p. 1, 1899.

[2] Kohlrausch and Holborn, l. c.

[3] Compare A. Hagenback, l. c., 5, p. 292.

Numerical Results.

Series I.

Potassium Iodide. Curve 1, Fig. 2.

$K = 0.1321$, $C = 0.01855$ *per cent.*, $W = 0.11169$ *g.*, $V = 0.3715$ *c.c.*

Liquid.			
t	$S \times 10^6$.	V_t/V	$S \cdot V_t/V \times 10^6$.
90.0	908.4	0.4324	392.8
102.0	1,006.0	.4363	438.9
123.0	1,098.0	.4451	488.2
138.2	1,126.0	.4548	511.9
149.0	1,139.0	.4674	532.3
159.0	1,126.0	.4764	536.2
171.0	1,076.0	.4853	522.5
183.8	1,006.0	.4979	500.9
197.0	740.4	.5095	377.3
208.5	617.0	.5137	314.3
220.0	431.2	.5445	234.8
225.0	337.5	.5569	187.9
230.0	252.1	.5693	143.5

Series II.

Potassium Iodide. Curve 1, Fig. 2; Curve 9, Fig. 3.

Constants of tube and of solution as in I. In Fig. 3 all curves are referred to the same critical temperature for the sake of convenience and comparison. The temperatures of series I. are those used as scale.

Liquid.			
t	$S \times 10^6$.	V_t/V	$S \cdot V_t/V \times 10^6$.
237.0	186.0	0.6005	111.6
238.0	157.6	.6094	96.05
238.5	143.7	.6183	88.88
239.0	127.0	.6275	79.69
239.5	107.5	.6362	68.39
240.04	83.71	.6628	55.50
240.4	63.92	.7432	47.50
240.5	55.46	.8074	44.78
240.6	45.29	.9566	43.32
Crit.	42.65	1.000	42.65

Gas.			
t	$S \times 10^6$.	t	$S \times 10^6$.
240.7	42.14	242.45	36.10
240.8	41.56	243.4	34.45
240.9	40.98	244.4	32.88
241.0	40.41	245.46	31.24
241.2	39.52	247.1	29.11
241.4	38.68	249.1	26.59
241.6	37.89	252.0	23.92
241.92	37.06		

SERIES III.

Ammonium Chloride. Curve 2, Fig. 2.

$K = 0.1316$, $C = 0.2245$ *per cent.*, *tube* 1/3 *full at* 20°.

Liquid.			
t	$S \times 10^6$.	V_t/V.	$S \cdot V_t/V \times 10^6$.
71.0	3,556.0	.3833	1,363.0
85.1	3,744.0	.3897	1,460.0
94.6	3,851.0	.3927	1,512.0
105.2	3,948.0	.4006	1,581.0
116.2	4,058.0	.4021	1,631.0
124.7	4,108.0	.4087	1,679.0
135.0	4,159.0	.4147	1,722.0
144.0	4,176.0	.4174	1,743.0
165.4	4,094.0	.4234	1,733.0
174.8	4,042.0	.4261	1,723.0
183.8	3,929.0	.4300	1,690.0
194.0	3,769.0	.4333	1,633.0
204.0	3,528.0	.4359	1,538.0
214.0	3,241.0	.4411	1,430.0
219.0	2,777.0	.4464	1,240.0
224.0	2,533.0	.4461	1,130.0
229.2	2,003.0	.4453	892.1

Series IV.

Ammonium Chloride. Curve 2, Fig. 2; Curve 8, Fig. 6. Constants of tube and solution as in III.

Liquid.			
t	$S \times 10^6$.	V_t/V	$S \cdot V_t/V \times 10^6$.
234.0	1,524.0	.4411	672.0
236.9	1,236.0	.4333	535.8
239.0	930.3	.4261	430.3
240.0	760.0	.4147	315.2
241.0	605.7	.4000	242.3
241.9	469.7	.3707	158.8
242.5	257.7	.2806	72.33

Vapor.		Gas.	
t	$S \times 10^6$.	t	$S \times 10^6$.
236.9	1.574	243.1	67.25
239.0	2.177	245.2	54.36
240.0	3.568	247.1	47.62
241.0	6.381	249.0	41.33
241.9	14.64	254.0	30.19
242.5	38.66		

Series V.

Potassium Iodide. Curve 3, Fig. 2.

The measurements in this series were obtained with a tube that had not been previously heated above room temperatures. They illustrate, therefore, the reaction that takes place between the solute and the solvent.

Constants of tube and quantity of solute as in I. $W = 0.10688$g.

Vapor.			
t	$S \times 10^6$.	t	$S \times 10^6$.
236.6	0.4220	241.4	2.118
239.0	.5521	241.7	3.449
240.1	.7482	241.8	3.785
241.1	1.544	241.9	6.091

Liquid.			
t	$S \times 10^6$.	V_t/V.	$S \cdot V/V \times 12^6$.
88.00	162.3	.4209	68.29
114.5	262.4	.4344	114.0
135.5	319.6	.4503	143.9
156.0	401.0	.4674	187.4
176.5	488.3	.4809	239.8
194.5	512.2	.4944	253.3
215.5	399.7	.5119	204.6
227.1	321.8	.5303	170.6
232.1	255.2	.5438	138.8
236.6	181.9	.5569	101.0
239.0	131.7	.5657	74.47
240.1	107.0	.5837	62.50
241.1	80.87	.6045	48.87
241.4	67.0	.6226	43.58
241.7	56.99	.6449	36.76
241.8	52.94	.6585	34.85
241.9	45.28	.6772	30.68
242.0	35.02	.8254	28.91

Series VI.

Potassium Iodide. Curve 10, Fig. 3.

The same tube and solution as in V., but after the solution has been heated until reaction is complete.

Liquid.			
t	$S \times 10^6$.	V_t/V.	$S \cdot V_t/V \times 10^6$.
237.1	170.2	.5555	94.58
239.1	131.4	.5657	74.35
240.1	106.9	.5749	61.46
241.1	80.34	.6070	48.76
241.6	77.07	.6365	37.54
241.8	50.86	.6770	34.43
241.9	44.46	.6952	30.98
242.0	37.56	.7537	28.31

Gas.			
t	$S \times 10^6$.	V_t/V	$S \times 10^6$.
242.1	28.64	244.1	24.29
242.22	28.21	245.1	23.05
242.4	27.43	246.1	22.08
242.6	26.77	247.1	21.26
242.8	26.23	249.1	19.70
243.0	25.81	252.1	17.67
243.5	25.20		

Series VII.

Potassium Iodide. Curve 4, Fig. 2.

$K = 0.1461$, $C = 0.209$ *per cent.*, $V = 0.431$ *c.c.*, $W = 0.122$ *g.*

Liquid.			
t	$S \times 10^6$.	V_t/V	$S \cdot V_t/V \times 10^6$.
78.2	1,416.0	.3534	500.2
89.0	1,497.0	.3599	538.9
99.6	1,553.0	.3638	565.0
109.5	1,663.0	.3667	615.1
120.2	1,718.0	.3700	647.1
129.3	1,753.0	.3767	666.2
139.5	1,781.0	.3801	688.9
149.5	1,796.0	.3868	700.4
170.4	1,717.0	.3933	686.0
179.2	1,622.0	.3967	653.6
199.2	1,388.0	.4134	578.2
208.5	1,163.0	.4167	488.7
219.1	923.4	.4201	387.9
224.8	790.0	.4167	329.2
234.0	575.8	.4134	238.0
236.0	480.4	.4034	193.7
238.0	378.5	.3933	148.9
239.0	313.7	.3868	121.4
240.0	239.1	.3599	86.06
241.0	165.9	.3100	51.40

Series VIII.

Potassium Iodide. Curve 4, Fig. 2; Curve 7, Fig. 6.

Constants of tube and solution as in VII.

Vapor.		Gas.	
t	$S \times 10^6$.	t	$S \times 10^6$.
235.0	0.6291	243.1	53.48
237.0	0.9230	245.1	47.42
239.0	1.988	247.0	42.86
240.0	3.561	250.3	37.25
241.0	7.575	255.2	32.15
242.0	18.65		

Series IX.

Potassium Iodide. Curve 5, Fig. 6.

The tube was filled one third full of solution. Owing to its concentration, the solution did not pass through the critical point, but

collected in the bottom, becoming very concentrated. At 259° there was only a trace of liquid left.

$K = 0.1461$, $C = 2.53$ *per cent.*

Vapor.			
t	$S \times 10^6$.	t	$S \times 10^6$.
234.0	1.500	251.0	49.30
237.2	1.899	253.0	69.26
239.6	2.432	255.0	82.31
243.1	6.135	257.0	104.2
245.0	11.01	259.0	125.3
247.0	16.84		

Series X.

Potassium Iodide. Curve 6, Fig. 6.

Same tube as in IX. with one half the solution removed. In this case the liquid disappeared by evaporating from the bottom of the tube.

Gas.			
t	$S \times 10^6$.	t	$S \times 10^6$.
249.0	1.188	257.0	2.247
251.0	1.360	259.5	5.979
254.0	1.718	262.2	15.49

Series XI.

Potassium Iodide. Curve 11, Fig. 3.

Constants of tube and quantity of solute as in I. $W = 0.09881$ g.

Liquid.			
t	$S \times 10^6$.	V_l/V.	$S \cdot V_l/V \times 10^6$.
238.2	148.6	.4639	68.95
239.2	123.5	.4677	57.79
240.2	91.41	.4685	42.83
240.7	69.04	.4693	32.40
240.9	60.49	.4624	27.97
241.0	55.27	.4535	25.07
241.1	48.39	.4444	21.50
241.2	39.29	.4064	15.97

Gas.

t	$S \times 10^6$.	t	$S \times 10^6$.
241.3	22.79	244.2	17.70
241.4	21.99	245.2	16.81
241.5	21.33	246.2	16.02
241.6	20.78	247.2	15.26
241.7	20.53	248.2	14.59
241.9	20.20	250.2	13.39
242.4	19.72	253.2	12.28
243.2	18.80		

Series XII.

Potassium Iodide. Curve 12, Fig. 3.

Constants of tube and quantity of solute as in I. $W = 0.09125$g.

Liquid.

t	$S \times 10^6$.	V/V_1.	$S \cdot V_1/V \times 10^6$.
239.9	153.1	.3905	59.80
240.9	116.9	.3905	45.66
241.4	92.76	.3905	36.23
241.6	84.94	.3811	32.41
241.8	75.01	.3725	27.95
241.9	70.77	.3547	25.09
242.0	60.98	.3367	20.53
242.1	48.01	.2898	13.92

Gas.

t	$S \times 10^6$.	t	$S \times 10^6$.
242.2	18.13	243.8	14.24
242.3	16.54	244.8	13.24
242.4	16.04	245.8	12.69
242.5	15.89	246.8	12.07
242.7	15.57	248.8	10.90
242.9	15.32	251.8	9.431
243.4	14.78		

Series XIII.

Potassium Iodide. Curve 13, Fig. 3.

Constants of tube and quantity of solute as in I. $W = 0.07142$g.

Liquid.			
t	$S \times 10^6$.	V_l/V	$S \cdot V_l/V \times 10^6$.
237.1	245.9	.2845	69.93
238.1	219.4	.2734	59.96
239.1	188.8	.2453	46.38
239.6	177.7	.2328	41.22
240.1	159.3	.2148	34.22
240.3	149.8	.2013	30.16
240.4	144.5	.1832	26.49

Vapor.		Gas.	
t	$S \times 10^6$.	t	$S \times 10^6$.
237.1	0.5795	241.7	6.785
238.1	0.7204	241.8	6.639
239.1	1.025	242.0	6.447
239.5	1.217	242.5	6.243
240.1	1.666	243.0	6.023
240.3	2.096	244.12	5.601
240.7	2.909	245.1	5.295
241.0	4.003	246.1	5.001
241.22	5.147	247.1	4.648
241.4	6.216	249.1	4.078
241.5	6.845	252.1	3.487
241.65	6.993		

Series XIV.

Potassium Iodide. Curve 14, Fig. 3.

A tube, constricted to a small capillary at the middle, was filled with solution so that at the critical point the tube was three fourths full of liquid. The tube was heated through the critical point without stirring. In the curve plotted no correction was made for change in volume of the liquid.

$K = 0.1393$, $C = 0.1188$ *per cent.*, $V = 0.464$ *c.c.*, $W = 0.1363$*g*.

t	$S \times 10^6$.	t	$S \times 10^6$.
238.0	422.5	241.5	169.0
238.9	367.0	241.6	152.7
239.9	299.2	241.8	142.8
240.6	253.1	242.0	136.7
241.0	218.4	242.2	132.3
241.2	197.6	242.6	122.1
241.3	183.9	243.1	112.1
241.4	178.0	243.6	108.2

Series XV.

Potassium Iodide. Curve 15, Fig. 4.

Series XV.–XX. were carried out with the same tube containing the same quantity of solute, and quantities of solvent as indicated.

$K = 0.2781$, $C = 0.1188$ *per cent.*, $V = 0.3981$*c.c.*, $W = 0.11636$*g*.

Gas.			
t	$S \times 10^6$.	t	$S \times 10^6$.
241.5	56.41	245.0	45.51
242.0	53.95	247.0	41.68
243.0	50.54	250.1	36.97
244.0	47.90		

Series XVI.

Potassium Iodide. Curve 16, Fig. 4.

Constants of tube and quantity of solute as in XV. $W = 0.1023$g.

Gas.			
t	$S \times 10^6$.	t	$S \times 10^6$.
241.32	42.24	245.0	28.80
242.0	36.35	247.0	25.79
243.0	32.48	250.0	22.04
244.0	30.59		

Series XVII.

Potassium Iodide. Curve 17, Fig. 4.

Constants of tube and quantity of solute as in XV. $W = 0.09684$g.

Gas.			
t	$S \times 10^6$.	t	$S \times 10^6$.
241.6	28.80	245.0	21.25
242.0	26.54	247.0	19.14
243.0	24.23	250.0	16.90
244.0	22.47		

Series XVIII.

Potassium Iodide. Curve 18, Fig. 4.

Constants of tube and quantity of solute as in XV. $W = 0.0815$g.

Gas.			
t	$S \times 10^6$	t	$S \times 10^6$.
241.7	16.56	245.0	7.886
242.0	10.09	247.0	7.081
243.0	9.396	250.0	6.003
244.0	8.626		

Series XIX.

Potassium Iodide. Fig. 4, Plate IV.

Constants of tube and quantity of solute as in XV. $W = 0.0758$g.

Gas.			
t	$S \times 10^6$.	t	$S \times 10^6$.
241.3	4.783	245.0	3.656
242.0	4.468	247.0	3.247
243.0	4.141	250.0	2.824
244.0	3.884		

Series XX.

Potassium Iodide. Curve 20, Fig. 4.

Constants of tube and quantity of solute as in XV. $W = 0.0588$g.

Gas.			
t	$S \times 10^6$.	t	$S \times 10^6$.
239.0	1.892	244.9	1.521
241.0	1.736	247.2	1.387
242.9	1.662	250.1	1.230

Series XXI.

From curves 15–20 the values of the specific conductivity were obtained for the temperatures 245° and 250°. These values are given below and are plotted with the quantities of solvent in curves 21 and 22, Fig. 5.

Solvent.	Density.	$S \times 10^6$	
		245°.	250°.
.1163 g.	.251	45.6	37.2
.1023	.220	28.8	22.0
.09684	.208	21.2	16.83
.0815	.178	8.0	6.0
.0758	.163	3.7	2.8
.0588	.127	1.44	1.2

(*To be Concluded.*)

A CONVENIENT METHOD OF MOUNTING CARBON RESISTANCES.

By Arthur W. Gray.

LONGDEN (Phys. Rev., Dec., 1902, p. 355) has shown how to make a fairly satisfactory high resistance by depositing soot on a plate of glass whose ends had previously been silvered with a wedge-shaped film. A modification of this, which can be very conveniently mounted, is illustrated in the accompanying figure.

A tube of glass is substituted for the plate. The ends after being silvered are snugly wrapped with a ribbon of stout tin foil, which is firmly bound on with copper wire so as to make good contact with the silver. Then the soot is deposited and hardened as described by Longden. To mount the resistance thus prepared, a J-shaped glass tube AB and a shorter U-shaped one CD are fastened vertically into a block of paraffin as indicated. The lower portions of these tubes are filled with mercury. The resistance tube is simply slipped over the long arm B of the J-tube and the end of the wire binding the tin foil at the top is carried down through B until it makes contact with the mercury; the end of the wire at the bottom dips into the mercury in C. The soot coating is protected by covering with a large test-tube, which is prevented from slipping about by means of the slightly smaller glass ring E fastened to the paraffin. A and D form the terminals.

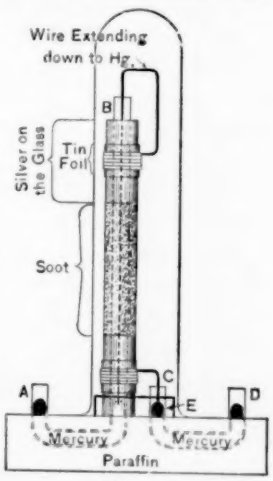

Fig. 1.

A block of wood or paraffin, into which are fastened vertically a number of glass tubes, can be conveniently used for storing a series of resistances of various magnitudes, so that when one is wanted, all that is necessary is to transfer it from the rack to the mounting.

Berlin, October 19, 1903.

NOTE.

George Gabriel Stokes. — George Gabriel Stokes was born in Ireland on August 13, 1819. His father, the Rev. Gabriel Stokes, was rector of the church in the little village of Skreen, Sligo Co., his mother being a daughter of the rector of Kilrea. He was sent for his early education to Dr. Wahl's school in Dublin and afterwards to the College in Bristol, whence in 1837 he proceeded to Cambridge, entering at Pembroke College. His life was henceforth fully identified with the interests of his college. He was elected to a fellowship just after taking his degree in 1841, and retained it until his marriage in 1857 to a daughter of the Rev. T. R. Robinson, D.D., Director of Armagh Observatory. Under the statutes of the university at that time in force, this event compelled him to vacate his fellowship, but he was reëlected in 1869 under the new statutes and only resigned in 1902, when he was 83 years old, to become Master of the College. His tenure of the latter post was short; he died on February 1, 1903.

Practically the whole of Stokes's scientific life was connected with the interests of two bodies — his University and the Royal Society. He graduated as senior wrangler in 1841, the first of the great triumvirate which attained the coveted honor in three successive years — Stokes, Cayley, Adams. There were giants in those days. Sylvester and George Green had taken their degrees in 1837 and Lord Kelvin followed in 1845, and chief amongst those of note in other lines, was Charles Kingsley, who took honors in mathematics and classics in 1842. This period was in reality not far removed from the time when British mathematics had been entirely isolated. Until the beginning of the century Newton's methods and fluxional notation were almost exclusively employed and it was only some ten years before Stokes matriculated that the influence of Woodhouse, aided later by Peacock, J. F. W. Herschel, Babbage, Whewell, Airy and others, was successful in completely establishing continental methods for examination purposes and in forcing the recognition of the mathematical work which had made such advances outside the country. Thus the men of the period, in the middle of which came Stokes, had the advantage of being trained by those who were thoroughly grounded in the old methods but who had spent time and energy in working up and introducing the new. Neither was the intellectual activity of the pioneers of the new movement confined to

research in mathematics. Text-books had been written setting forth the continental methods, and translations of foreign works had been made. A classical tripos had been established in 1824, but all candidates who went in for it were required to have taken honors previously in mathematics — a rule abolished in 1850.

The mathematical power of Stokes began to show itself immediately. His first paper was published the year after he took his degree and the decade which followed was certainly the most fruitful of his life in regard to the equality and quantity of the work which has come directly from his pen. The Royal Society Catalogue contains the titles of over fifty papers printed within this period, and many of these are not only of far-reaching importance but mark the beginnings of his researches into almost every department of mathematical physics — hydrodynamics, light, elastic solids, the mathematical expression of wave motion by Fourier's series, sound and conduction of heat. Modest as he was concerning his own achievements, he thought nearly all of these papers sufficiently good to be included in his collected works, the first three volumes of which cover this period alone. To mention a few of the most important, we have the researches "On the Steady Motion of Incompressible Fluids" and "On the Theories of the Internal Friction of Fluids in Motion, and of the Equilibrium and Motion of Elastic Solids," with a "Supplement," which together constitute the complete foundation of the hydrokinetics of the present day. In the paper "On the Effect of the Internal Friction of Fluids on the Motion of Pendulums," he considers and works out the effect of viscosity on various kinds of motion. Deep sea waves and the solitary wave are very fully treated in the memoir "On the Theory of Oscillatory Waves." But the theory of light was the subject in which he seems to have been most willing to work. The two papers "On the Dynamical Theory of Diffraction," and "On the Change of Refrangibility of Light," in the latter of which fluorescence is described and explained, would have alone sufficed to make his reputation.

Two further papers, "On the Critical Values of the Sums of Periodic Series" and "On the Numerical Calculation of a Class of Definite Integrals and Infinite Series," must be mentioned, not only because of their great intrinsic value, but also because they show that the author was right abreast of the developments in pure mathematics at that time and that he was able to advance them and use them as an instrument of research for the investigation of physical problems.

This last fact is perhaps worth insisting on at the present time, when the separation between pure mathematics and physics has become far wider than is advantageous for either. The physicist works mainly in his laboratory, the mathematician at his desk, neither entrenching on the domain of the other. Even the magnificent work of Poincaré, introduc-

ing the rigorous and fruitful methods of pure mathematics for the treatment of physical problems, is only a partial step in the right direction. With Stokes this divorce never occurred; experiment went hand in hand with theory. As early as 1840 he had fitted up a small laboratory in his rooms, of simple character it is true, but none the less sufficient to test, sometimes searchingly, the results of his theories. And it was the same all through his life. He was never content to leave a theory unconfirmed by experiment, and if a new observation were made it must be compared with theory. These qualities are especially noticeable in some of his earlier papers. In that on internal friction, he explains the suspension of clouds and the subsidence of ripples and waves after a storm; in those on oscillatory wave motion, the well-known experiments of Scott Russell are fully considered; his paper on diffraction is divided into two parts consisting of his theory and of the experiments which he made to test it, and so on. Later in life he would, in a short note or a few remarks, give the main outline of an explanation of some new phenomenon; further research by others usually proved him to be correct.

This active period quickly brought recognition to him. In 1849 he succeeded to the Lucasian chair of mathematics in Cambridge, a post held previously by Isaac Barrow, Newton, Woodhouse, Airy and Babbage, and five years later he was elected secretary to the Royal Society. He was not content with delivering the two courses of lectures required of the professor by the regulations. He let it be known that he considered it part of his duty to help students in their work, and such help from a man like Stokes was not to be despised. He was always ready to give assistance, whether it was asked for work already started, or in suggesting new problems to be undertaken, or in giving encouragement where failure seemed likely. This trait was even more conspicuous during his thirty-one years' tenure of the Royal Society position. Naturally brought into contact with all the best work which was being done throughout the country, he largely gave himself up to helping others. This was undoubtedly the main reason for the smaller output after this time. As against 50 papers produced up to 1852, we find only 56 from then until the end of 1883, and many of the latter consist of addresses and short notes on such subjects as chemistry, details of instruments, and history of science, all valuable but perhaps not epoch-making like the earlier memoirs. His reward was the frequent acknowledgment of his assistance which those alone who had received knew how to appreciate. A generous tribute is given by Lord Kelvin[1] of his own indebtedness, and a further one by an anonymous writer,[2] who tells that though he was previously quite unknown, some work of his attracted the attention of Stokes

[1] Nature, February 12, 1903.
[2] *Ibid.*, February 19, 1903.

and a correspondence was started in the course of which on one particular day he received as many as three letters and a telegram! It is unnecessary to say a word on the quality of the assistance given. It was the same throughout; knowledge and time were always at the disposal of small and great.

It has been said that much of Stokes's work was given to others, and indeed some of it was never published in scientific journals at all. An instance of this occurs with reference to the transformation of a line integral into a surface integral which he put as a question in a Smith's prize examination paper in 1854. Again, he had thought out the physical basis of the solar spectrum some seven years before Kirchhoff, and had been in the habit of lecturing on it. Stokes deprecated any attempt to obtain for himself the credit of this discovery, saying that he had failed to take an essential step in the process. It is possible that the papers he left behind will tell even more of his own work than we know now, and they will doubtless add much to the scientific history of the second half of the last century.

Amongst other honors, Stokes received the Rumford medal in 1852, the Copley medal in 1893, was Burnett Lecturer 1883–5, Gifford Lecturer 1890–2, and was created a baronet in 1889 when Lord Salisbury was prime minister.

In 1885, Stokes received the highest scientific honor which England has to bestow — the Presidency of the Royal Society; this he held until 1890. From 1887–1892 he represented the University in Parliament. Being still Lucasian Professor, he thus attained the unique distinction of holding the three positions simultaneously. Only once before had one man, Isaac Newton, occupied them all, and in his case the tenures were at different periods of his life. In 1899, Cambridge University fittingly celebrated the jubilee of his election as professor, inviting representatives from all parts of the world and publishing a memorial volume of the Transactions of the Cambridge Philosophical Society a body to which many of his papers had been communicated. Although at this time about to enter his eighty-first year, he seemed able to endure fatigue without showing signs of his advanced age. On the chief day set apart by the university, he attended morning and afternoon congregations of the senate, a lunch, and a late banquet, and the following day was early in London to attend a committee, only closing his labors on various matters late that night.

A word must be said concerning Stokes's relation to religious questions, partly because they evidently entered much into his thoughts and formed an essential part of his character, and partly because during the last twenty years of his life there were published addresses and papers on the question by him. On several occasions he spoke before the

Church Congress, the Victoria Institute and other bodies on the relation between science and faith. What value is to be set on these, this is not the place to discuss; it is sufficient to mention that he took a prominent part in the efforts made in England in educating the public to higher views of the relations of science to theology, and in rescuing the study of the former from the doubtful position which it had, even among some of the more advanced students of religious questions. His own personality and the methods of treatment which he adopted were always on the side of promoting good feeling and tending towards the prevention of acrimonious discussion amongst those whose opinions differed most widely. He avoided, as a rule, dogmatic statements and treated the questions in his usual scientific manner, allowing his own opinions to be inferred rather than expressly stated.

The published portraits of Stokes, representing him with a somewhat severe type of countenance, fail to bring out a characteristic expression. Ordinarily silent in society, he would freely talk on any subject that interested him. While telling of some remarkable fact or observation, the broad high forehead would pucker into a thousand wrinkles and a smile would light up his face with a brilliancy which seemed to show a concentrated picture of the whole man. Those who had the privilege of listening to his highly-finished and carefully worded lectures on the wave-theory of light delivered without a note, or of watching the simple experiments and diagrams with which he illustrated them, will remember how eagerly they looked for the first symptoms of this change. The lectures, too, were characteristic. Toward the end of the course, evidently wishing to give more than was possible in the limited time, he would continue further and further over the allotted hour until the last day when, on one occasion, amid the gradual disappearance of the class to fulfill other engagements, he kept those who remained interested for nearly three hours.

There was but little apparent failure of Stokes's physical and intellectual powers until within a few days of his death at the age of eighty-three. He died as he had lived — in harness — and a great figure passed away from the scene at the close of a well-rounded and successful career. His work, mainly on wave-motion and the tranformations which, in its different forms, it undergoes under various circumstances, has already taken a permanent place in the history of science. And he has left behind with those who knew him a memorial of himself which will not be easily effaced.

E. W. B.

NEW BOOKS.

Mineralogy. By HENRY A. MIERS. London and New York, The Macmillan Company, 1902. Pp. 584.

The limitations in the scope of this text-book are perhaps best indicated by a quotation from the preface: "The student will not find in the following pages any systematic account of the modes of occurrence of minerals, their geological distribution, their origin, their alterations, or their artificial reproductions." These topics are set aside as deserving to form a separate volume.

The matter selected for treatment in the book is taken up in two parts: I., The Properties of Minerals, and II., Description of the More Important Mineral Species. The most extensive chapters in Part I. are those dealing with "The Crystalline Form" and "The Optical Properties of Crystals." Both these topics are treated with accuracy and with a distinct originality in the method of presentation. In the opinion of the reviewer, these chapters are suited to supplement rather than to supplant the more usual styles of treatment. In the matter of obliterating the sharp distinction between the conceptions *crystal* and *mineral*, which should exist in the mind of the student, and doubtless does exist in the mind of the author, the book bears an unfortunate similarity to many of its predecessors. In most cases emphasis is laid on actual determinations of the various physical properties of minerals by the student, and much attention is given to the apparatus and methods for making these determinations. In this respect the book is suggestive but not at all exhaustive. Especial mention might be made of the attention given to specific heat, also of the discussions upon the relations between the properties of minerals, etc.

In Part II. the aim is to describe the more common species rather fully, omitting the rarer minerals entirely. Consequently only about 250 of the 1,000 known varieties and species are mentioned. The descriptions are interesting to an unusual degree, and lay especial stress on the peculiarities which can be readily observed by the learner. The classification of species is not readily comprehensible. For instance, mica and tourmaline are placed in the section entitled "Silicates Containing Halogens," while topaz and sodalite are not included. Many such instances could be cited.

With all its lack of logical development in the arrangement of details, the book may be characterized as accurate, suggestive, original in method, and distinctly progressive in matters pertaining to crystallography. Its usefulness as a book of reference has been purposely sacrificed in order to attain greater efficiency as a text-book, yet the tables of physical properties — index of refraction, double refraction, optical angle and specific gravity — will be found helpful to many besides the beginners in mineralogy.

A word should be added with regard to the illustrations. They have in a remarkable degree the property of *illustrating*. Even in the rare instances where there are flagrant inaccuracies of execution (*e. g.*, Fig. 271), the main idea is clearly conveyed.

On the whole, this new text-book seems well adapted to improving the quality of instruction given in the subject of mineralogy.

A. C. GILL.

A Laboratory Manual of Physics. By H. C. CHESTON, P. R. DEAN and C. E. TIMMERMAN. New York, American Book Co., 1902. Pp. 128.

This book, written to meet the needs of the high schools of New York, has found its way into a larger circle of readers. The experiments here described are 72 in number and are distributed as follows: To the mechanics of solids, 22; of liquids, 6; of air, 5; to sound, 3; to heat, 9; to light, 8; to electricity and magnetism, 22. Many of the exercises are identical with those found in Hall and Bergen's book. The large majority of the exercises are quantitative in character. They are aimed to meet the requirements of Harvard University; of the syllabus of the Middle States Examination Board and that of the regents of New York State. Each experiment includes a statement of the object of the exercise, the apparatus needed, directions for work, a tabular form for recording the measurements and a conclusion. The tabular forms suggesting methods of record are a very valuable feature of the book. The directions are clear, concise and logical. Experience shows that some of the exercises are too long for the time that can ordinarily be assigned to them. This is true of Ex. 5, "The relation between the weight of a displaced liquid and the loss of weight of the solid." This should be separated into two. Some experiments, *e. g.*, Ex. 9, "To determine the pressure of the air on a square centimeter of surface" would better be performed on the lecture table. Many illustrations and cuts are given and a table of physical constants and trigonometric functions is added.

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